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D. G. Grabowska P. Kavanagh

September 1993



## **Incorporating Radial Mixing in Axisymmetric Streamline Curvature Through-flow Analysis**

**Final Technical Report** 

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Turbomachinery
Components Research Program

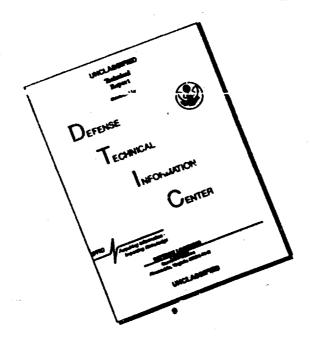
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## Incorporating Radial Mixing in Axisymmetric Streamline Curvature Through-flow Analysis

**Final Technical Report** 

D. G. Grabowska P. Kavanagh

Department of Mechanical Engineering lowa State University

September 1993

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#### **ABSTRACT**

Based on the original development of radial mixing effects by Gallimore, the development of the governing equations for hub-to-tip streamline curvature solutions in tubomachinery passages and blade rows and incorporating viscous radial mixing is presented. Arbitrary passage geometries and quasi-orthogonal descriptions are accounted for. FORTRAN program coding is carried out for the special case of unbladed, axial-flow passages. Flow solutions are obtained by iteration based on fixed streamline patterns in the meridional plane followed by further iterations involving readjustment of the streamlines until overall convergence is obtained. Simple examples are presented to illustrate the solution technique. This work was carried out under AFOSR Grant F49620-92-J-0026.

#### **SYMBOLS AND NOTATION**

A, B B E <sub>n</sub> , E <sub>0</sub> , E <sub>m</sub> f <sub>n</sub> , f <sub>o</sub> , f <sub>m</sub> f <sub>p</sub> g H h i j k m m r T T	Parameter used to integrate the momentum equation unit vector tangent to the mean blade surface and which lies in the q-0 plane at an angle $\epsilon$ from the q-0 direction viscous body force components distributed blade body force components force vector normal to the blade surface gravitational acceleration stagnation enthalpy static enthalpy quasi-orthogonal index streamline index heat transfer coefficient meridional direction mass flow rate normal direction static pressure radial direction stagnation pressure static temperature avial direction
$V_z, V_m, V_\theta, V_\theta$	axial direction V, velocities
Sc Pr	Schmidt number $Sc = \mu/(\rho\epsilon)$ Prandtl number $Pr = \mu c_p/k$
u, v,	unit vectors normal strain rates
$e_{nm}, e_{n\theta}, e_{m\theta}$	shear strain rates
r <sub>c</sub> q s	radius of curvature heat flux entropy
GREEK B	angle measured from the meridional direction to a unit vector tangent to the turbomachine blade (see Fig. A1) quasi-orthogonal lean angle measured from the radial direction

$\epsilon$	mixing coefficient
θ	tangential direction
$\mu$	viscosity
ρ	density
$\sigma_{\rm nn},~\sigma_{\rm 60},~\sigma_{\rm mm}$	stess tensor comonenets
$\phi$	angle measured from the axial direction to a line tangent to a streamline
Φ	viscous dissipation function

.

#### 1. INTRODUCTION

For many years, axisymmetric solutions obtained from streamline curvature analyses have been a standard approach in analyzing axial compressor or turbine design and performance. In this approach, the flow calculations are reduced as a practical consideration to a mathematically two-dimensional problem in which the through-flow is assumed to be steady, inviscid, and confined to concentric stream surfaces. As a result, no transport of mass, momentum, or energy takes place across these concentric surfaces, and thus no accounting of essentially three-dimensional effects is made due to secondary flows, blade or endwall boundary layer flows, or tip leakage flows. In particular, comparisons with detailed interstage traverses have shown that calculated results do not accurately model radial profiles of stagnation temperature, pressure, and flow angle as the profiles develop through the machine. Thus inclusion of spanwise mixing terms in the through-flow calculations would serve as important function in improving the modeling of radial profiles and allow more realistic modeling of losses. Streamline curvature calculations are carried out in an iterative fashion to satisfy momentum and continuity requirements along quasi-orthogonals established in the two-dimensional field. These calculations have proved to be acceptable in terms of stability and convergence, at least in the case of hub-to-tip solutions conducted in the meridional plane. This quasi 3-D approach is very likely to continue as the standard method of aerodynamic analysis in turbomachinery for some years to come, although fully 3-D codes are used on occasion to further refine details of the flow.

Practical approaches to account for secondary flow effects have had a considerably heuristic goal in devising reasonably simple but adequate models. Wennerstrom (1991), in reviewing modeling ideas that have been proposed over the last 20 or 25 years, points out that an approach based on transport phenomena has been used to superimpose semiempirical models of secondary flow features as corrections to otherwise classical axisymmetric solutions. Wennerstrom has termed these modeling attempts as hybrid solutions since they are not truly two-dimensional, nor are they fully three-dimensional. By necessity, the objective is not to deal with the three-dimensional details of the flow, but to deal with the overall computation for arbitrary geometries. The major contributors to the modeling efforts in recent years have been Adkins and Smith (1982), who proposed that secondary flows were responsible for spanwise mixing, and Gallimore and Cumpsty (1986), who viewed turbulent diffusion, rather than secondary flow, to be the dominant mechanism of spanwise mixing. Leylek and Wisler (1991) have, through extensive numerical analysis and experiments, largely resolved the issue of the dominant mixing mechanism. They concluded that the relative importance of secondary flow and turbulent diffusion depend "non stage loading, solidity, and aspect ratio. Thus, it would appear that both mechanisms should be incorporated in the performance calculation process. It is worth noting that if one is able to predict with reasonable assurance the performance of a given machine, then one has the most powerful design tools available. Howard and Gallimore (1992) extended the turbulent diffusion model of Gallimore and Cumpsty (1986) to include a viscous wall.

The objective of the research described in this work was to develop the governing equations for hub-to-tip flow analysis in intrinsic coordinates using the streamline curvature throughflow method incorporating the turbulent diffusion model of spanwise mixing developed by Gallimore and Cumpsty.

A special case of the governing equations for unbladed, axial-flow passages was then used to create a FORTRAN computer program to demonstrate the iterative solution technique.

#### 2. GOVERNING EQUATIONS FOR HUB-TO-TIP FLOW ANALYSIS

#### 2.1 The Momentum Equations

Turbomachinery flow is viscous, compressible, unsteady, and highly three-dimensional. One method often used in turbomachinery design and analysis is to assume steady, axisymmetric flow through the annular passage, allowing the flow to be treated in terms of a so-called hub-to-tip analysis in the meridional plane. Thus the flow analysis is reduced to one involving only two space dimensions. In the case of bladed regions, these flow simplifications are equivalent to assuming an infinite number of infinitely thin blades.

Figure 2.1 shows the meridional plane; a cylindrical coordinate system  $(r, \theta, z)$  is indicated with the z axis aligned along the axis of the machine, and r pointing in the radial direction. The  $\theta$  or tangential direction points out of the paper normal to the meridional plane. Also shown in Figure 2.1 is an intrinsic coordinate system  $(n, \theta, m)$  with the m and n coordinates lying in the plane. The m coordinate corresponds to the meridional streamlines in the flow, and the n coordinate is orthogonal to them. Thus the flow velocity can be expressed as

$$\vec{V} = \vec{V}_m + \vec{V}_\theta \tag{2.1}$$

where  $V_m$  is the meridional velocity, and  $V_0$  is the tangential velocity. The angle  $\phi$  is the slope of the streamlines measured from the z-axis, and  $\ell_m$  are unit vectors along the

m and n coordinate directions. The  $(n, \theta, m)$  coordinates will be used in the development of the analysis which follows.

In Figure 2.2, the meridional plane is shown again with representative hub and tip boundaries of the annulus, and with rotor and stator blade rows included. In intrinsic coordinates, the normal, tangential, and meridional momentum equations may be written (Tsien, 1958) as

$$\rho \left[ \frac{V_{\theta}^{2}}{r} \cosh - V_{m}^{2} \frac{\partial \Phi}{\partial m} \right] = \frac{\partial \sigma_{mn}}{\partial m} + \frac{\partial \sigma_{nn}}{\partial n} + \sigma_{mn} \left( \frac{\sin \Phi}{r} + \frac{\partial \Phi}{\partial n} \right)$$

$$+ \sigma_{nm} \frac{\partial \Phi}{\partial n} + \sigma_{nn} \left( \frac{\cos \Phi}{r} - \frac{\partial \Phi}{\partial m} \right)$$

$$- \sigma_{\theta\theta} \frac{\cos \Phi}{r} - \sigma_{mm} \frac{\partial \Phi}{\partial m} + \rho f_{n}$$

$$(2.2)$$

$$\rho \frac{V_m}{r} \frac{\partial (r V_\theta)}{\partial m} = \frac{\partial \sigma_{m\theta}}{\partial m} + \frac{\partial \sigma_{n\theta}}{\partial n} + \sigma_{m\theta} \left( \frac{\sin \phi}{r} + \frac{\partial \phi}{\partial n} \right) + \sigma_{\theta m} \frac{\sin \phi}{r}$$

$$+ \sigma_{n\theta} \left( \frac{\cos \phi}{r} - \frac{\partial \phi}{\partial m} \right) + \sigma_{\theta n} \frac{\cos \phi}{r} + \rho f_\theta$$
(2.3)

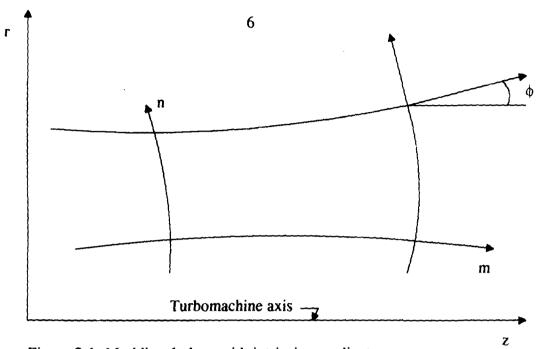


Figure 2.1 Meridional plane with intrinsic coordinate system

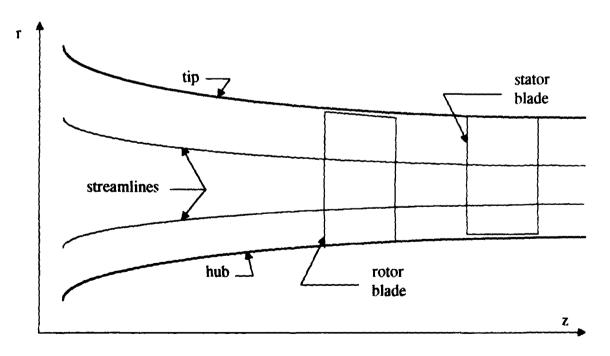


Figure 2.2 Turbomachine geometry

$$\rho \left[ V_m \frac{\partial V_m}{\partial m} - \frac{V_\theta^2}{r} \sin \phi \right] = \frac{\partial \sigma_{mm}}{\partial m} + \frac{\partial \sigma_{nm}}{\partial n} + \sigma_{mm} \left( \frac{\sin \phi}{r} + \frac{\partial \phi}{\partial n} \right) + \sigma_{mn} \left( \frac{\cos \phi}{r} - \frac{\partial \phi}{\partial m} \right) + \sigma_{mn} \frac{\partial \phi}{\partial m} - \sigma_{nn} \frac{\partial \phi}{\partial n}$$

$$- \sigma_{\theta\theta} \frac{\sin \phi}{r} + \rho f_m$$
(2.4)

where  $\rho$  is density, the various  $\sigma$  terms are the stress tensor components, the f terms are distributed blade body forces, and  $V_m$ ,  $V_0$ ,  $\phi$ , and r are as previously defined. See Appendix A for the derivation of the distributed blade body force components.

The stress-strain rate relationships for a compressible fluid may be found in White (1991). Using thermodynamic pressure and viscosity, the stress-strain rate relationships written in terms of the intrinsic coordinates  $(n, \theta, m)$  are:

$$\sigma_{nn} = -p + 2\mu e_{nn}$$

$$\sigma_{\theta\theta} = -p + 2\mu e_{\theta\theta}$$

$$\sigma_{mm} = -p + 2\mu e_{mm}$$

$$\sigma_{nm} = \sigma_{mn} = 2\mu e_{nm}$$

$$\sigma_{n\theta} = \sigma_{\theta n} = 2\mu e_{n\theta}$$

$$\sigma_{m\theta} = \sigma_{\theta m} = 2\mu e_{m\theta}$$

$$\sigma_{m\theta} = \sigma_{\theta m} = 2\mu e_{m\theta}$$

The strain rates may be expressed as functions of the velocity gradients (White, 1991). Substituting for the strain rates in Eqn. (2.5), the stress-strain rate equations take the form:

$$\sigma_{nn} = -p + 2 \mu V_m \frac{\partial \phi}{\partial n}$$

$$\sigma_{\theta\theta} = -p + 2 \mu \frac{V_m}{r} \sin \phi$$

$$\sigma_{mm} = -p + 2 \mu \frac{\partial V_m}{\partial m}$$

$$\sigma_{nm} = \sigma_{mn} = \mu \left( \frac{\partial V_m}{\partial n} - V_m \frac{\partial \phi}{\partial m} \right)$$

$$\sigma_{n\theta} = \sigma_{\theta n} = \mu \left( \frac{\partial V_{\theta}}{\partial n} - \frac{V_{\theta}}{r} \cos \phi \right)$$

$$\sigma_{m\theta} = \sigma_{\theta m} = \mu \left( \frac{\partial V_{\theta}}{\partial m} - \frac{V_{\theta}}{r} \sin \phi \right)$$

$$(2.6)$$

These expressions for the stresses may be substituted into Eqns. (2.2) – (2.4), leaving the equations of motion as functions of p,  $\rho$ ,  $\phi$ ,  $\mu$ ,  $V_m$  and  $V_0$ , and  $f_n$ ,  $f_0$ , and  $f_m$ .

As an approach to viscous analysis of hub-to-tip flows, Gallimore (1985) proposed a spanwise mixing model in cylindrical coordinates of the velocity and temperature fields by retaining in the momentum equations the normal stresses,  $\sigma_{rr}$ ,  $\sigma_{ee}$ ,  $\sigma_{zz}$ , and only the shear stresses acting on the inner and outer cylindrical surfaces of the fluid element,  $\sigma_{re}$  and  $\sigma_{rz}$ . He argued also that, because mixing is assumed to occur across the cylindrical surfaces, the normal strain rates in the axial and tangential directions ( $e_{zz}$  and  $e_{ee}$ ) could be neglected. Heat transfer due to mixing would be modeled by retaining only radial temperature gradients in the energy equation.

A spanwise mixing model for intrinsic coordinates may be derived in a similar fashion with mixing assumed to occur across the meridional stream surfaces. Therefore,

the shear stresses  $\sigma_{n\theta}$  and  $\sigma_{nm}$  are retained while the remaining shear stresses are neglected and the normal stresses,  $\sigma_{nn}$ ,  $\sigma_{mm}$ , and  $\sigma_{\theta\theta}$ , are retained with the strain rates  $e_{mm}$  and  $e_{\theta\theta}$  neglected. Heat transfer due to mixing is modeled by retaining only normal temperature gradients in the energy equation. Figure 2.3 shows a fluid element in intrinsic coordinates with the stress terms retained by the spanwise mixing model. The momentum equations obtained from Eqns. (2.2) – (2.4) and (2.6) incorporating the spanwise mixing model in intrinsic coordinates are:

$$\rho \left[ \frac{V_{\theta}^{2}}{r} \cos \phi - V_{m}^{2} \frac{\partial \phi}{\partial m} \right] = -\frac{\partial p}{\partial n} + 2 \frac{\partial \left( \mu V_{m} \frac{\partial \phi}{\partial n} \right)}{\partial n} + \mu \frac{\partial \phi}{\partial n} \left( \frac{\partial V_{m}}{\partial n} - V_{m} \frac{\partial \phi}{\partial m} \right)$$

$$+ 2 \mu V_{m} \frac{\partial \phi}{\partial n} \left( \frac{\cos \phi}{r} - \frac{\partial \phi}{\partial m} \right) + \rho f_{n}$$
(2.7)

$$\rho \frac{V_m}{r} \frac{\partial (rV_{\theta})}{\partial m} = \frac{\partial \left(\mu r \frac{\partial}{\partial n} \left(\frac{V_{\theta}}{r}\right)\right)}{\partial m} + \mu r \frac{\partial \left(\frac{V_{\theta}}{r}\right)}{\partial n} \left(\frac{\cos \phi}{r} - \frac{\partial \phi}{\partial m}\right) + \rho f_{\theta}$$
 (2.8)

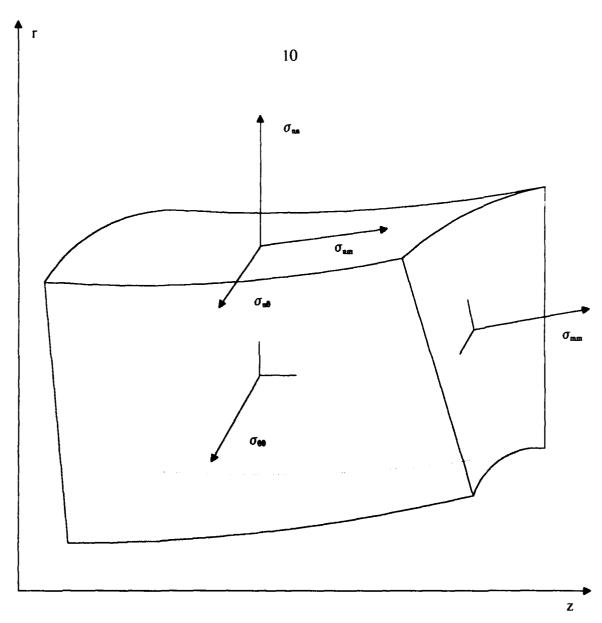


Figure 2.3. Fluid element for mixing model

$$\rho \left[ V_m \frac{\partial V_m}{\partial m} - \frac{V_\theta^2}{r} \sin \phi \right] = -\frac{\partial p}{\partial m} + \frac{\partial \left[ \mu \left( \frac{\partial V_m}{\partial n} - V_m \frac{\partial \phi}{\partial m} \right) \right]}{\partial n} + \mu \left( \frac{\partial V_m}{\partial n} - V_m \frac{\partial \phi}{\partial m} \right) \left( \frac{\cos \phi}{r} - \frac{\partial \phi}{\partial m} \right) - 2 \mu V_m \left( \frac{\partial \phi}{\partial n} \right)^2 + \rho f_m$$
(2.9)

The notation in these equations may be simplified to

$$V_m^2 \frac{\partial \Phi}{\partial m} - \frac{V_\theta^2}{r} \cos \Phi = -\frac{1}{\rho} \frac{\partial p}{\partial n} + E_n + f_n \qquad (2.10)$$

$$\frac{V_m}{r} \frac{\partial (rV_\theta)}{\partial m} = E_\theta + f_\theta \tag{2.11}$$

$$V_{m} \frac{\partial V_{m}}{\partial m} - \frac{V_{\theta}^{2}}{r} \sin \phi = -\frac{1}{\rho} \frac{\partial p}{\partial m} + E_{m} + f_{m} \qquad (2.12)$$

where the  $E_n$ ,  $E_0$ , and  $E_m$  terms represent viscous body forces per unit mass and are written as:

$$E_{n} = \frac{1}{\rho} \left[ 2 \frac{\partial \left( \mu V_{m} \frac{\partial \Phi}{\partial n} \right)}{\partial n} + \mu \frac{\partial \Phi}{\partial n} \left( \frac{\partial V_{m}}{\partial n} - V_{m} \frac{\partial \Phi}{\partial m} \right) + 2 \mu V_{m} \frac{\partial \Phi}{\partial n} \left( \frac{\cos \Phi}{r} - \frac{\partial \Phi}{\partial m} \right) \right]$$

$$E_{\theta} = \frac{1}{\rho} \left[ \frac{\partial \left( \mu r \frac{\partial}{\partial n} \left( \frac{V_{\theta}}{r} \right) \right)}{\partial n} + \mu r \frac{\partial \left( \frac{V_{\theta}}{r} \right)}{\partial n} \left( \frac{\cos \Phi}{r} - \frac{\partial \Phi}{\partial m} \right) \right]$$

$$E_{m} = \frac{1}{\rho} \left[ \frac{\partial \left( \mu \left( \frac{\partial V_{m}}{\partial n} - V_{m} \frac{\partial \Phi}{\partial m} \right) \right)}{\partial n} + \mu \left( \frac{\partial V_{m}}{\partial n} - V_{m} \frac{\partial \Phi}{\partial m} \right) \left( \frac{\cos \Phi}{r} - \frac{\partial \Phi}{\partial m} \right) \right]$$

$$- \left( \frac{\partial \Phi}{\partial n} \right)^{2} 2 \mu V_{m} \right]$$
(2.13)

#### 2.2 The Radial Equilibrium Equation

The determination of flow variables in the meridional plane is accomplished by the iterative solution of the uncoupled momentum and continuity equations. The solution of the normal and meridional momentum equations is complicated by the fact that both the n and m directions change throughout the flow field as the computation approaches convergence. The flow field solution may be simplified by constructing fixed quasi-orthogonal (q-o) coordinates approximately perpendicular to the streamlines. The n direction may then be eliminated by transforming the momentum equations to the m and q-o directions. A flow field grid is then formed by the streamlines and the quasi-orthogonals. Figure 2.4 shows the coordinate systems in the meridional plane, including

the defined q-o. The angle,  $\gamma$ , between the r and q-o directions is taken to be positive when measured as shown.

The chain rule for a function of two variables may be written to express the directional derivative along the q-o as:

$$\frac{\partial(\ )}{\partial q} = \frac{\partial(\ )}{\partial n} \frac{\mathrm{d}n}{\mathrm{d}q} + \frac{\partial(\ )}{\partial m} \frac{\mathrm{d}m}{\mathrm{d}q}$$
 (2.14)

In addition, the following geometric relationships can be found from Figure 2.4:

$$\frac{\partial n}{\partial q} = \cos(\phi + \gamma) \qquad \frac{\partial m}{\partial q} = \sin(\phi + \gamma) \qquad (2.15)$$

Combining Eqns. (2.14) and (2.15) and solving for  $\partial()/\partial n$  yields

$$\frac{\partial()}{\partial n} = \sec(\phi + \gamma) \frac{\partial()}{\partial q} - \tan(\phi + \gamma) \frac{\partial()}{\partial m}$$
 (2.16)

This relationship is used in the development below to transform the momentum component equations to the (m, q) coordinate system.

From Gibbs' Tds relationship we can write

$$\frac{\mathrm{d}p}{\rho} = -T\mathrm{d}s + \mathrm{d}H - V\mathrm{d}V \tag{2.17}$$

where H is the stagnation enthalpy and V is the flow velocity. The pressure gradients in

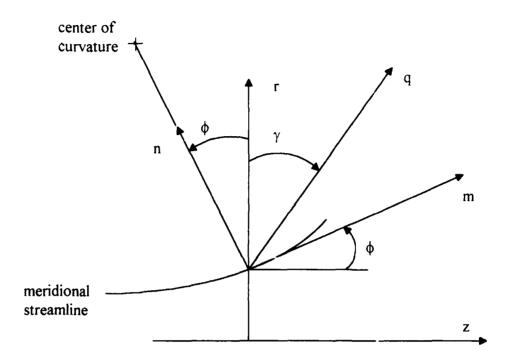


Figure 2.4. The (m, n), (r, z), and (m, q) coordinate systems in the meridional plane

the m and n directions therefore are

$$\frac{1}{\rho} \frac{\partial p}{\partial m} = -T \frac{\partial s}{\partial m} + \frac{\partial H}{\partial m} - V \frac{\partial V}{\partial m}$$

$$\frac{1}{\rho} \frac{\partial p}{\partial n} = -T \frac{\partial s}{\partial n} + \frac{\partial H}{\partial n} - V \frac{\partial V}{\partial n}$$
(2.18)

Substituting Eqns (2.18) into the normal and meridional momentum equations, Eqns. (2.10) and (2.12), the momentum equations become:

$$V_{m} \frac{\partial V_{m}}{\partial m} - \frac{V_{\theta}^{2}}{r} \sin \phi = -\frac{\partial H}{\partial m} + V_{m} \frac{\partial V_{m}}{\partial m} + V_{\theta} \frac{\partial V_{\theta}}{\partial m} + T \frac{\partial s}{\partial m} + E_{m} + f_{m}$$

$$V_{m}^{2} \frac{\partial \phi}{\partial m} - \frac{V_{\theta}^{2}}{r} \cos \phi = -\frac{\partial H}{\partial n} + V_{m} \frac{\partial V_{m}}{\partial n} + V_{\theta} \frac{\partial V_{\theta}}{\partial n} + T \frac{\partial s}{\partial n} + E_{n} + f_{n}$$
(2.19)

Using Eqn. (2.16) to replace the n directional gradients in the normal momentum equation with gradients in the m and q directions, we obtain

$$V_{m}^{2} \frac{\partial \Phi}{\partial m} - \frac{V_{\theta}^{2}}{r} \cos \Phi = -\sec(\Phi + \gamma) \frac{\partial H}{\partial q} + \tan(\Phi + \gamma) \frac{\partial H}{\partial m}$$

$$+ T \sec(\Phi + \gamma) \frac{\partial s}{\partial q} + T \tan(\Phi + \gamma) \frac{\partial s}{\partial m}$$

$$+ V_{m} \sec(\Phi + \gamma) \frac{\partial V_{m}}{\partial q} + V_{m} \tan(\Phi + \gamma) \frac{\partial V_{m}}{\partial m}$$

$$+ V_{\theta} \sec(\Phi + \gamma) \frac{\partial V_{\theta}}{\partial q} + V_{\theta} \tan(\Phi + \gamma) \frac{\partial V_{\theta}}{\partial m}$$

$$+ E_{n} + f_{n}$$

$$(2.20)$$

The m and n momentum equations may now be combined by multiplying the m momentum equation by  $tan(\phi + \gamma)$  and adding the result to the n momentum equation. Further rearrangement gives

$$\tan(\phi + \gamma) \left[ V_m \frac{\partial V_m}{\partial m} - \frac{V_{\theta}^2}{r} \sin\phi - E_m - f_m \right] + V_m^2 \frac{\partial \phi}{\partial m} - \frac{V_{\theta}^2}{r} \cos\phi =$$

$$-\sec(\phi + \gamma) \frac{\partial H}{\partial q} + \sec(\phi + \gamma) T \frac{\partial s}{\partial q} + \sec(\phi + \gamma) V_{\theta} \frac{\partial V_{\theta}}{\partial q} +$$

$$E_n + f_n + \sec(\phi + \gamma) V_m \frac{\partial V_m}{\partial q}$$
(2.21)

Multiplying Eqn. (2.21) by  $\cos(\phi + \gamma)$  and rearranging gives:

$$V_{m} \frac{\partial V_{m}}{\partial q} = \sin(\phi + \gamma) V_{m} \frac{\partial V_{m}}{\partial m} + \cos(\phi + \gamma) V_{m}^{2} \frac{\partial \phi}{\partial m} + \frac{\partial H}{\partial q} - T \frac{\partial s}{\partial q}$$

$$- \sin(\phi + \gamma) (E_{m} + f_{m}) - \cos(\phi + \gamma) (E_{n} + f_{n}) \qquad (2.22)$$

$$- \cos(\phi + \gamma) \cos\phi \frac{V_{\theta}^{2}}{r} - \sin(\phi + \gamma) \sin\phi \frac{V_{\theta}^{2}}{r} - V_{\theta} \frac{\partial V_{\theta}}{\partial q}$$

The radius of curvature,  $r_c$ , of the meridional streamline is defined by:

$$\frac{1}{r_c} = \frac{\partial \Phi}{\partial m} \tag{2.23}$$

Using this result in Eqn (2.22) along with further rearrangement, and recognizing that  $\partial r/\partial q = \cos \gamma$ , we get the final form of radial equilibrium equation

$$V_{m} \frac{\partial V_{m}}{\partial q} = \sin(\phi + \gamma) V_{m} \frac{\partial V_{m}}{\partial m} + \cos(\phi + \gamma) \frac{V_{m}^{2}}{r_{c}} + \frac{\partial H}{\partial q} - T \frac{\partial s}{\partial q}$$

$$- \sin(\phi + \gamma) [E_{m} + f_{m}] - \cos(\phi + \gamma) [E_{n} + f_{n}] - \frac{V_{\theta}}{r} \frac{\partial (rV_{\theta})}{\partial q}$$
(2.24)

Equation (2.16) may be used to eliminate the n directional gradient terms in the normal, tangential, and meridional viscous body force equations, leaving

$$E_{n} = \frac{1}{\rho} \left\{ 2 \sec(\phi + \gamma) \frac{\partial}{\partial q} \left[ \mu V_{m} \left( \sec(\phi + \gamma) \frac{\partial \phi}{\partial q} - \tan(\phi + \gamma) \frac{\partial \phi}{\partial m} \right) \right] - 2 \tan(\phi + \gamma) \frac{\partial}{\partial m} \left[ \mu V_{m} \left( \sec(\phi + \gamma) \frac{\partial \phi}{\partial q} - \tan(\phi + \gamma) \frac{\partial \phi}{\partial m} \right) \right] + \left( 2.25 \right) \right]$$

$$\mu \left( \sec(\phi + \gamma) \frac{\partial V_{m}}{\partial q} - \tan(\phi + \gamma) \frac{\partial V_{m}}{\partial m} - V_{m} \frac{\partial \phi}{\partial m} \left( \sec(\phi + \gamma) \frac{\partial \phi}{\partial q} - \tan(\phi + \gamma) \frac{\partial \phi}{\partial m} \right) + 2 \mu V_{m} \frac{\partial \phi}{\partial m} \left( \frac{\cos\phi}{r} - \frac{\partial \phi}{\partial m} \right) \right\}$$

$$E_{\theta} = \frac{1}{\rho} \left\{ \sec(\phi + \gamma) \frac{\partial}{\partial q} \left[ \mu r \left( \sec(\phi + \gamma) \frac{\partial}{\partial q} \left( \frac{V_{\theta}}{r} \right) - \tan(\phi + \gamma) \frac{\partial}{\partial m} \left( \frac{V_{\theta}}{r} \right) \right) \right] - \tan(\phi + \gamma) \frac{\partial}{\partial m} \left[ \mu r \left( \sec(\phi + \gamma) \frac{\partial}{\partial q} \left( \frac{V_{\theta}}{r} \right) - \tan(\phi + \gamma) \frac{\partial}{\partial m} \left( \frac{V_{\theta}}{r} \right) \right) \right] + \mu r \left( \frac{\cos\phi}{r} - \frac{\partial\phi}{\partial m} \right) \left( \sec(\phi + \gamma) \frac{\partial}{\partial q} \left( \frac{V_{\theta}}{r} \right) - \tan(\phi + \gamma) \frac{\partial}{\partial m} \left( \frac{V_{\theta}}{r} \right) \right) \right\}$$

$$(2.26)$$

$$E_{m} = \frac{1}{\rho} \left\{ \sec(\phi + \gamma) \frac{\partial}{\partial q} \left[ \mu \left( \sec(\phi + \gamma) \frac{\partial V_{m}}{\partial q} - \tan(\phi + \gamma) \frac{\partial V_{m}}{\partial m} - V_{m} \frac{\partial \phi}{\partial m} \right) \right] - \tan(\phi + \gamma) \frac{\partial}{\partial m} \left[ \mu \left( \sec(\phi + \gamma) \frac{\partial V_{m}}{\partial q} - \tan(\phi + \gamma) \frac{\partial V_{m}}{\partial m} - V_{m} \frac{\partial \phi}{\partial m} \right) \right] + \mu \left( \frac{\cos\phi}{r} - \frac{\partial\phi}{\partial m} \right) \left( \sec(\phi + \gamma) \frac{\partial V_{m}}{\partial q} - \tan(\phi + \gamma) \frac{\partial V_{m}}{\partial m} - V_{m} \frac{\partial\phi}{\partial m} \right) \right\}$$

$$- 2 \mu V_{m} \left( \sec(\phi + \gamma) \frac{\partial\phi}{\partial q} - \tan(\phi + \gamma) \frac{\partial\phi}{\partial m} \right)^{2}$$

Because momentum and temperature mixing are assumed to occur only in the normal direction, the terms in the viscous body force equations which contain velocity gradients in the meridional direction will be neglected, leaving

$$E_{n} = \frac{1}{\rho} \left\{ 2 \sec(\phi + \gamma) \frac{\partial}{\partial q} \left[ \mu V_{m} \left( \sec(\phi + \gamma) \frac{\partial \phi}{\partial q} - \tan(\phi + \gamma) \frac{\partial \phi}{\partial m} \right) \right] - 2 \tan(\phi + \gamma) \frac{\partial}{\partial m} \left[ \mu V_{m} \left( \sec(\phi + \gamma) \frac{\partial \phi}{\partial q} - \tan(\phi + \gamma) \frac{\partial \phi}{\partial m} \right) \right] + \mu \left( \sec(\phi + \gamma) \frac{\partial V_{m}}{\partial q} - V_{m} \frac{\partial \phi}{\partial m} \right) \left( \sec(\phi + \gamma) \frac{\partial \phi}{\partial q} - \tan(\phi + \gamma) \frac{\partial \phi}{\partial m} \right) + 2 \mu V_{m} \frac{\partial \phi}{\partial m} \left( \frac{\cos\phi}{r} - \frac{\partial \phi}{\partial m} \right) \right\}$$

$$= \frac{1}{\rho} \left\{ \sec(\phi + \gamma) \frac{\partial}{\partial q} \left[ \mu r \left( \sec(\phi + \gamma) \frac{\partial}{\partial q} \left( \frac{V_{\theta}}{r} \right) - \frac{V_{\theta}}{r^{2}} \tan(\phi + \gamma) \frac{\partial r}{\partial m} \right) \right]$$

$$E_{\theta} = \frac{1}{\rho} \left\{ \sec(\phi + \gamma) \frac{\partial}{\partial q} \left[ \mu r \left( \sec(\phi + \gamma) \frac{\partial}{\partial q} \left( \frac{V_{\theta}}{r} \right) - \frac{V_{\theta}}{r^2} \tan(\phi + \gamma) \frac{\partial r}{\partial m} \right) \right] - \tan(\phi + \gamma) \frac{\partial}{\partial m} \left[ \mu r \left( \sec(\phi + \gamma) \frac{\partial}{\partial q} \left( \frac{V_{\theta}}{r} \right) - \frac{V_{\theta}}{r^2} \tan(\phi + \gamma) \frac{\partial r}{\partial m} \right) \right] + \mu r \left( \frac{\cos\phi}{r} - \frac{\partial\phi}{\partial m} \right) \left( \sec(\phi + \gamma) \frac{\partial}{\partial q} \left( \frac{V_{\theta}}{r} \right) - \frac{V_{\theta}}{r^2} \tan(\phi + \gamma) \frac{\partial r}{\partial m} \right) \right\}$$

$$(2.29)$$

$$E_{m} = \frac{1}{\rho} \left\{ \sec(\phi + \gamma) \frac{\partial}{\partial q} \left[ \mu \left( \sec(\phi + \gamma) \frac{\partial V_{m}}{\partial q} - V_{m} \frac{\partial \phi}{\partial m} \right) \right] - \tan(\phi + \gamma) \frac{\partial}{\partial m} \left[ \mu \left( \sec(\phi + \gamma) \frac{\partial V_{m}}{\partial q} - V_{m} \frac{\partial \phi}{\partial m} \right) \right] + \mu \left( \frac{\cos\phi}{r} - \frac{\partial\phi}{\partial m} \right) \left( \sec(\phi + \gamma) \frac{\partial V_{m}}{\partial q} - V_{m} \frac{\partial\phi}{\partial m} \right) - 2 \mu V_{m} \left( \sec(\phi + \gamma) \frac{\partial\phi}{\partial q} - \tan(\phi + \gamma) \frac{\partial\phi}{\partial m} \right)^{2} \right\}$$

$$(2.30)$$

In the iterative solution of the radial equilibrium equation, the first two terms on the right hand side of Eqn. (2.24) use values of  $V_m$ ,  $\phi + \gamma$ , and  $r_c$  from a previous solution of the flow field. In order to close the system, equations are needed for the entropy and stagnation enthalpy gradients. These equations are derived in the following sections.

#### 2.3 The Energy Equation

Expressed in terms of enthalpy, the energy equation may be written:

$$\rho \frac{Dh}{Dt} = \frac{Dp}{Dt} - \nabla \cdot \vec{q} + \Phi \qquad (2.31)$$

where  $\vec{q}$  is heat flux and  $\Phi$  is the dissipation function. Gibbs' *Tds* relationship, Eqn. (2.17), may be used to eliminate the pressure derivative in the energy equation yielding:

$$\rho T \frac{Ds}{Dt} = -\nabla \cdot \vec{q} + \Phi \qquad (2.32)$$

The left hand side of this equation may be expanded by using the definition of the substantial derivative, which, due to the assumption of steady flow, yields

$$\rho T \frac{Ds}{Dt} = \rho T V_m \frac{\partial s}{\partial m} = -\nabla \cdot \vec{q} + \Phi \qquad (2.33)$$

The intrinsic coordinate forms of the del operator and the divergence are needed in

order to expand the heat transfer term. The del operator is defined as

$$\nabla = \hat{e}_m \frac{\partial}{\partial m} + \hat{e}_n \frac{\partial}{\partial n} \tag{2.34}$$

Retaining only the *n* directional temperature gradients,  $\nabla T$  gives

$$\nabla T = \hat{e}_n \frac{\partial T}{\partial n} \tag{2.35}$$

Assuming that conduction is modeled by Fourier's Law, the gradient of the heat flux may expanded to give

$$\nabla \cdot (-k) \nabla T = \nabla (-k) \cdot \nabla T + (-k) \nabla \cdot \nabla T \qquad (2.36)$$

where k is the coefficient of thermal conductivity. The coordinate system geometry gives the following relationships for the derivatives of the unit vectors

$$\frac{\partial \hat{e}_n}{\partial m} = -\frac{\partial \Phi}{\partial m} \hat{e}_m \qquad \frac{\partial \hat{e}_n}{\partial n} = -\frac{\partial \Phi}{\partial n} \hat{e}_m \qquad (2.37)$$

Combining Eqn. (2.34) - (2.37) gives

$$-\nabla \cdot \vec{q} = -\nabla \cdot (-k\nabla T) = -k \frac{\partial \Phi}{\partial m} \frac{\partial T}{\partial n} + \frac{\partial}{\partial n} \left(k \frac{\partial T}{\partial n}\right)$$
 (2.38)

The second term on the right hand side of the energy equation, Eqn. (2.31), is the dissipation function, which, written in terms of strain rates (Hughs and Gaylord, 1964)

for the intrinsic coordinates,  $(n, \theta, m)$  is

$$\Phi = \mu \left\{ 2(e_{nn}^2 + e_{\theta\theta}^2 + e_{mm}^2) + (2e_{n\theta})^2 + (2e_{nm})^2 + (2e_{\theta m})^2 \right\}$$
 (2.39)

The dissipation function may be simplified by using the mixing model assumption in which the normal strain rates and  $\partial V/\partial m$  may be neglected. With these assumptions, the dissipation function becomes:

$$\Phi = \mu \left\{ \left[ \frac{\partial V_{\theta}}{\partial n} - \frac{V_{\theta}}{r} \cosh \right]^{2} + \left[ \frac{\partial V_{m}}{\partial n} - V_{m} \frac{\partial \Phi}{\partial m} \right]^{2} + \left[ \frac{V_{\theta}}{r} \sinh \right]^{2} \right\}$$
(2.40)

Substituting Eqns. (2.38) and (2.40), the energy equation, Eqn. (2.31) may be written:

$$\frac{\partial s}{\partial m} = -\frac{k}{\rho T V_m} \frac{\partial \phi}{\partial m} \frac{\partial T}{\partial n} + \frac{1}{\rho T V_m} \frac{\partial}{\partial n} \left( k \frac{\partial T}{\partial n} \right) + \frac{\Phi}{\rho T V_m} + \frac{\partial S_e}{\partial m}$$
 (2.41)

where  $\partial Se/\partial m$  is an empirically based entropy gradient which accounts for losses generated by flow over the blades.

Equation (2.16) is used to transform Eqn. (2.38) from the (n, m) to the (m, q) coordinate system yielding

$$\frac{\partial s}{\partial m} = -\frac{k}{\rho T V_m} \frac{\partial \phi}{\partial m} \left\{ \sec(\phi + \gamma) \frac{\partial T}{\partial q} \right\} + \frac{\sec(\phi + \gamma)}{\rho T V_m} \frac{\partial}{\partial q} \left\{ k \sec(\phi + \gamma) \frac{\partial T}{\partial q} \right\} 
- \frac{\tan(\phi + \gamma)}{\rho T V_m} \frac{\partial}{\partial m} \left\{ k \sec(\phi + \gamma) \frac{\partial T}{\partial q} \right\} 
+ \frac{\mu}{\rho T V_m} \left\{ \left[ \sec(\phi + \gamma) \frac{\partial V_{\theta}}{\partial q} - \frac{V_{\theta}}{r} \sin\phi \right]^2 + \left[ \sec(\phi + \gamma) \frac{\partial V_m}{\partial q} - V_m \frac{\partial \phi}{\partial m} \right]^2 
+ \left[ \frac{V_{\theta}}{r} \sin\phi \right]^2 \right\} + \frac{\partial S_e}{\partial m}$$
(2.42)

#### 2.4 The Stagnation Enthalpy Equation

The definition of stagnation enthalpy may be combined with Gibbs' *Tds* relationship to give

$$\frac{1}{\rho} \frac{\partial p}{\partial m} = \frac{\partial H}{\partial m} - V_m \frac{\partial V_m}{\partial m} - V_\theta \frac{\partial V_\theta}{\partial m} - T \frac{\partial s}{\partial m}$$
 (2.43)

Substituting Eqn. (2.43) into the meridional momentum equation, Eqn. (2.12), yields

$$\frac{V_{\theta}^{2}}{r}\sin\phi = \frac{\partial H}{\partial m} - T\frac{\partial s}{\partial m} - V_{\theta}\frac{\partial V_{\theta}}{\partial m} + E_{m} + f_{m} \qquad (2.44)$$

Solving Eqn. (2.44) for  $\partial H/\partial m$  and recognizing that  $\sin \phi = \partial r/\partial m$  gives

$$\frac{\partial H}{\partial m} = T \frac{\partial s}{\partial m} + \frac{1}{2r^2} \frac{\partial (r V_{\theta})^2}{\partial m} + E_m + f_m \qquad (2.45)$$

#### 2.5 The Angular Momentum Equation

Multiplying the tangential momentum equation, Eqn. (2.11), by  $V_0/V_m$  and rearranging yields a form of the angular momentum equation convenient for use with the stagnation enthalpy, Eqn. (244), and radial equilibrium, Eqn. (2.24) equations:

$$\frac{1}{2r^2}\frac{\partial (rV_{\theta})^2}{\partial m} = \frac{V_{\theta}}{V_m}(E_{\theta} + f_{\theta}) \qquad (2.46)$$

#### 2.6 Closure of the System of Equations

In the preceding sections, seven equations have been developed from the three component momentum equations and the energy equation. These equations are:

E <sub>n</sub> viscous body force	Eqn. (2.28)
E <sub>0</sub> viscous body force	Eqn. (2.29)
E <sub>m</sub> viscous body force	Eqn. (2.30)
Radial equilibrium	Eqn. (2.24)
Energy/entropy	Eqn. (2.42)
Meridional momentum/enthalpy	Eqn. (2.45)
Angular momentum	Eqn. (2.46)

Additional equations are needed to close the system of equations.

An equation for density may be derived by integrating Gibbs' Tds relationship to give

$$s = c_p \ln T - R \ln p \tag{2.47}$$

where s is the entropy, R is the gas constant, and  $c_p$  is the specific heat at constant pressure. An arbitrary reference state of s=0 at T=1 and p=1 was used for integration of the Tds relationship. Combining Eqn (2.47) with the ideal gas equation of state yields

$$\rho = \frac{T^{\frac{c_p-R}{R}}e^{-\frac{s}{R}}}{R} \tag{2.48}$$

The definition of stagnation enthalpy may be rearranged to give the temperature equation

$$T = \frac{H}{c_p} - \frac{V_m^2 + V_\theta^2}{2c_p}$$
 (2.49)

The streamline slope,  $\phi$ , and the q-o angle,  $\gamma$ , are determined from the streamlines and input quasi-orthogonal geometry (see Fig 2.4) by

$$\phi = \tan^{-1} \frac{\partial r}{\partial z} \Big|_{m}$$

$$\gamma = \tan^{-1} \frac{\partial z}{\partial r} \Big|_{q}$$
(2.50)

Through specification of the Prandtl number, Pr, the Schmidt number, Sc, and the mixing coefficient,  $\epsilon$ , the viscosity and heat transfer coefficient may be determined by

$$\mu = Sc \rho \epsilon$$

$$k = \frac{\mu c_p}{Pr}$$
(2.51)

The mixing coefficient is a function of the blade and annulus geometry and the turbomachine operating conditions. Those interested in more details on the calculation of  $\epsilon$  are referred to Gallimore (1985) and Schlichting (1979).

The distributed blade body forces,  $f_n$ ,  $f_0$ , and  $f_m$ , required in Eqns. (2.24), (2.45), and (2.46), depend on blade geometry for their calculation (See Appendix A).

For a given streamline pattern, the seven equations listed above combined with Eqns. (2.48) - (2.51) constitute a complete set of equations for streamline curvature analysis. The input variables required for this system are the Schmidt and Prandtl number, the mixing coefficient, the constant pressure specific heat, the gas constant, and the empirical entropy gradient as determined from blade geometry and flow conditions.

#### 2.7 Inlet Conditions

A consistent set of initial conditions is needed to start the iterative solution of the flow field. The following assumptions are made at the inlet to the flow annulus:

- 1. The inlet station q-o is assumed to be radial; therefore, angle  $\gamma = 0$  and  $\partial q$  may be replaced by  $\partial r$  in the system of equations (See Fig. 2.4).
- 2. The flow is inviscid and isentropic prior to reaching the inlet. As a result of this assumption, Eqns. (2.28), (2.29), (2.30), (2.42), and (2.45) reduce to zero, identically.
- 3. Streamlines at the inlet station are assumed to be flat, i.e.,  $\phi = 0$ ,  $r_c = \infty$ , and  $V_m = V_z$  (See Fig. 2.4).
- 4. There are no blades at the inlet station.
- 5. Stagnation temperature and pressure are assumed to be constant across the inlet station; therefore, H and s are also constant across the inlet.

These assumptions result in a reduced set of equations for the inlet.

Using the assumptions listed above, the radial equilibrium equation, Eqn. (2.24), reduces to the simple radial equilibrium equation

$$V_z \frac{\partial V_z}{\partial r} = -\frac{V_\theta}{r} \frac{\partial (rV_\theta)}{\partial r}$$
 (2.52)

Equations (2.47) - (2.49) and (2.51), used to compute entropy, density, temperature, viscosity, and the heat transfer coefficient, remain unchanged.

If the inlet velocity profile contains no  $V_0$  component (zero whirl at the inlet), the right hand side of Eqn. (2.52) reduces to zero and the axial velocity,  $V_2$ , must be constant across the inlet.

For the case of the inlet velocity profile containing an arbitrary  $V_0$  distribution with radius, Eqn. (2.52) must be integrated across the inlet to give the profile of the axial velocity,  $V_z$ .

The continuity equation is integrated across the inlet from streamline to streamline to obtain the mass flow rate which is used to satisfy continuity for the remaining q-os. The streamline to streamline integration also allows the computation of the fraction of the mass flow which passes between the hub and each streamline outward towards the outer casing. The radial location of each streamline is adjusted as necessary to maintain the same mass flow fraction as occurred at the inlet station. Details of the mass flow integration are covered in a following section.

#### 2.8 Solution Procedure for the Governing Equations in Bladed Flow Regions

The flow annulus of a turbomachine may be divided into unbladed and bladed regions with the bladed regions further divided into rotor and stator blade rows. The solution procedure for spanwise mixing based on streamline curvature through-flow analysis for bladed regions is outlined as follows:

1. The velocities, velocity gradients, and streamline pattern from a previous iteration or initial solution estimate are used to compute the viscous body forces,  $E_n$ ,  $E_0$ , and  $E_n$ , from Eqns. (2.28) - (2.30), and the distributed blade body forces,  $f_n$ ,  $f_0$ ,

- and  $f_m$ , from Eqns. (A4) and (A5) in Appendix A.
- 2. The temperature data obtained from the temperature field in a previous iteration or initial solution estimate are combined with the empirical entropy gradient, the velocity gradients and the streamline pattern to solve the energy equation, Eqn. (2.42), for the meridional entropy gradient along each streamline.
- 3. The angular momentum equation, Eqn. (2.43), is solved to give the meridional gradient of angular momentum along each streamline.
- 4. Using the gradients determined from the energy and angular momentum equations in steps 2 and 3, and the meridional body force,  $E_m$ , determined in step 1, the meridional gradient of stagnation enthalpy is computed for each streamline using Eqn. (2.41).
- 5. The entropy, angular momentum, and stagnation enthalpy values are then updated for each streamline and q-o intersection using the gradients determined above.
- 6. The temperatures and densities are updated for each intersection using Eqns. (2.48) and (2.49). The entropy, stagnation enthalpy, and velocity gradients in the q-o direction are then computed using the data determined in step 5.
- 7. The radial equilibrium equation is integrated to give the meridional velocity distribution,  $V_{\bullet}$ , along each q o.
- 8. The new  $V_m$  velocity profile computed in step 7 is used in the integration of the continuity equation at each q-o. The mass flow rate thus determined is used to adjust the constant of integration in step 7 as needed to achieve the same annulus

mass flow as was determined at the inlet station. The solution procedure iterates on steps 7 and 8 until the difference between the mass flow rates at each q-o and the inlet lies within an arbitrarily chosen tolerance.

- 9. The streamline radial locations are adjusted by interpolating the mass flow distributions to maintain same fraction of mass flow between the hub and each streamline as at the inlet station.
- 10. Overall convergence of the solution is determined by comparing the streamline shifts between successive iterations for the flow field with an arbitrarily chosen tolerance. If the streamline shifting is within the tolerance, the flow field solution has converged. If not, the streamline pattern is updated with the results of step 9 and the solution repeated again starting at step 1.
- 2.9 Solution Procedure for the Governing Equations in Unbladed Flow Regions
  The solution procedure for bladed regions differs from the unbladed regions only
  by the inclusion of the blade body forces and the empirical entropy gradient.

# 3. SOLUTION METHOD, COMPUTER PROGRAM DEVELOPMENT AND OPERATION

The governing equations developed in Chapter 2 are written in finite difference form and programmed for iterative solution. The computer program was developed for a blade-free annulus with inviscid and adiabatic endwalls. The annulus is essentially axial with the *q-os* directed radially from the hub to the outer casing. The governing equations are in the form derived by Gallimore (1985) which are a special case of the equations given in Chapter 2.

The following describes the main program involved and the associated subroutines which have been developed. Figure 3.1 is a mapping of the main program and the subroutines called. As stated previously, the solution is iterative with the sequence of execution essentially from left to right across the figure. Execution is repeated numerous times until convergence is obtained and Subroutine OUTPUT is called to print the solution results.

The complete FORTRAN code for the program is contained in Appendix C.

Comment lines in the main program and subroutines include a glossary of the FORTRAN variable names used.

## 3.1 Main Program and Control of the Calculations

The primary purpose of the main program is to control the order in which the subroutines are called to carry out a solution. The main program also prints statements which list the subroutine currently being executed and the number of iterations completed.

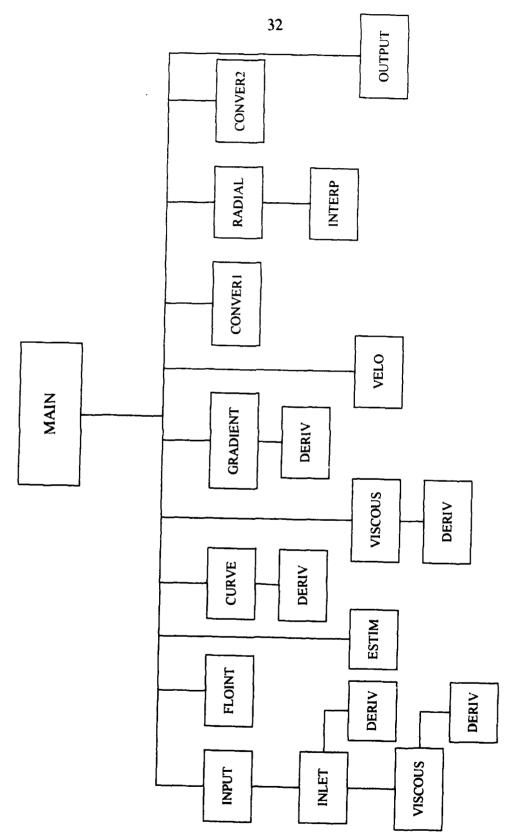


Figure 3.1 Main program and subroutine map

Subroutine INPUT reads the input data for the inlet station q-0 and then calls Subroutine INLET as shown in Fig. 3.1. Subroutine INLET computes values for the flow field variables such as static enthalpy and entropy. Subroutine INLET in turn calls DERIV to compute required first and second derivative values for flow field variables. Subroutine VISCOUS is called by INPUT to compute the viscous body forces,  $E_{\theta}$  and  $E_{z}$ , and the dissipation function,  $\Phi$ .

Subroutine FLOINT calculates the mass flow rate and fraction of mass flow rate between adjacent streamlines based on the inlet q-o input data.

Subroutine ESTIM initializes the downstream flow field variables and streamline pattern based on the inlet q-o input data and the hub and casing geometry. Note that INPUT, FLOINT, and ESTIM are called only once at the start of program execution.

Subroutines CURVE through RADIAL comprise the iterative portion of the program for the q-os downstream of the inlet station and implement the solution procedure outlined in Sections 2.8 and 2.9. A global iteration consists of one pass through the annulus executing Subroutines VISCOUS through CONVER1 for all the downstream q-os with the streamline radial locations held constant and is completed once the change in meridional velocity from one pass to the next is less than a user chosen tolerance as determined by Subroutine CONVER1. Subroutines RADIAL and INTERP then compute the new streamline locations for the converged velocity field.

A universal iteration consists of executing Subroutines CURVE through CONVER2 for all the downstream q-os. After a global iteration, CONVER2 is called to

check for streamline convergence which is determined by comparing the streamline shifts between successive universal iterations with an arbitrarily chosen tolerance. If convergence has not been attained, the main program starts a new universal iteration at Subroutine CURVE. Once the flow field has converged, Subroutine OUTPUT is called to print the converged flow field values to an output data file.

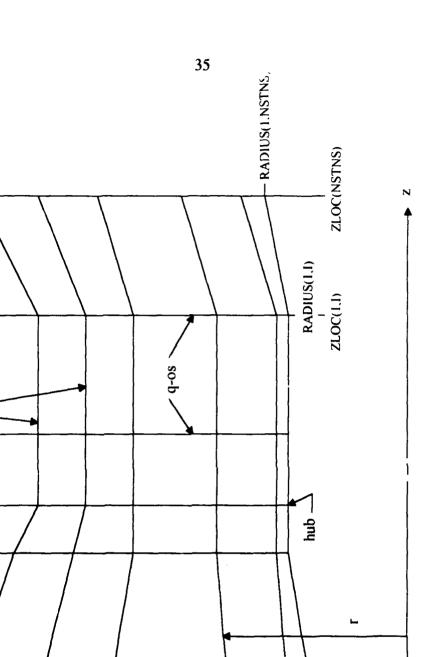
## 3.2 Subroutine Descriptions

Each subroutine listing in Appendix C contains a glossary of the FORTRAN variable names used as well as descriptions of the input required and the variables calculated as output. The following descriptions contain the finite difference formulations used.

Subroutine INPUT opens an existing unformatted data file called *input1.dat* and reads the data required by the program. Figure 3.2 shows the meridional plane with arbitrary hub and casing shapes and the FORTRAN variables used in *input1.dat*.

Stagnation temperature and pressure, represented by FORTRAN variables *TEMPIN* and *PRESIN*, are assumed to be constant across the inlet station. *MIXCO*, the mixing coefficient described in Chapter 2, is a function of blade and annulus geometry and the turbomachine operating conditions. *NSTRM* is the number of streamlines in the flow field and *NSTNS* is the number of *q-os*. The index variable, J, identified the streamlines, and I identifies the quasi-orthogonals, as shown in Fig. 3.2.

The user supplies the radial location of each streamline at the inlet station, RADIUS(J, l). The tangential velocity for each streamline, VTHETA(J, l), and the axial



RADIUS(NSTRM.NSTNS)

RADIUS(NSTRM.I)

streamlines \_\_

inlet q-o —

casing

RADIUS(NSTRM, 1)

Figure 3.2. Meridional plane, and required hub, casing, streamline, and q-o geometry. (Input flow variables at the inlet q-o are TEMPIN, PRESIN, MIXCO and whirl distibution VTHETA(1,1)... VTHETA(NSTRM,1))

ZLOC(1)

RADIUS(1,1)\_

RADIUS(J, I)

velocity, VMID, at a middle streamline which is determined by

$$JMID = INT\left(\frac{NSTRM}{2}\right) + 1 ag{3.1}$$

The streamline spacing prescribed at the inlet from hub to casing is arbitrary.

The q-os in the flow field are limited to the radial direction, although the z direction spacing is arbitrary. The axial location of each q-o is specified by ZLOC(I) and the radial location of the hub and casing on the q-o by RADIUS(1,1), and RADIUS(NSTRM,1). The arrangement of the data in file input1.dat is explained in comments included with Subroutine INPUT in Appendix C.

Subroutine INLET computes the flow properties for the inlet q-o using Eqns.

(2.47) to (2.49). The flow is assumed to be inviscid and adiabatic prior to reaching the inlet, and the streamlines at the inlet are take to be straight and parallel to the z axis. For a blade-free annulus with radial q-os, the simple radial equilibrium equation give in Eqn. (2.52) applies.

Integration of Eqn. (2.52) along the inlet q-o results in the following expressions for the axial velocity,  $V_c$ :

$$V_{z_{j}}^{2} = V_{z_{j-1}}^{2} - \frac{(r_{j} - r_{j-1})}{2} \left[ \frac{1}{r_{j-1}} \frac{\partial (rV_{\theta})^{2}}{\partial r} + \frac{1}{r_{j}} \frac{\partial (rV_{\theta})^{2}}{\partial r} \right] \qquad (j = j_{mid+1}...NSTRM) \quad (3.2)$$

$$V_{z_{j}}^{2} = V_{z_{j+1}}^{2} - \frac{(r_{j} - r_{j+1})}{2} \left[ \frac{1}{r_{j+1}} \frac{\partial (rV_{\theta})^{2}}{\partial r} + \frac{1}{r_{j}} \frac{\partial (rV_{\theta})^{2}}{\partial r} \right] \qquad (j = j_{mid-1} \dots 1)$$
 (3.3)

The integration results in Eqn. (3.3) proceed from the middle streamline, where  $V_z = VMID$ , to the casing, and in Eqn. (3.4) from the middle streamline to the hub, stepping streamline by streamline. The gradient terms in Eqns. (3.3) and (3.4) are determined in Subroutine DERIV as explained below.

The static temperature, entropy, and density for the inlet q-o are determined using Eqns. (2.47) to (2.49) in the forms:

$$T_{j} = T^{\circ} - \frac{V_{z_{j}}^{2} + V_{\theta_{j}}^{2}}{2 c_{p}}$$

$$s_{j} = c_{p} \ln(T^{\circ}) - R \ln(p^{\circ}) \qquad (j = 1...NSTRM)$$

$$\rho_{j} = \frac{T_{j}^{\frac{c_{p} - R}{R}} e^{\frac{-s_{j}}{R}}}{R}$$
(3.4)

Subroutine DERIY contains the finite difference schemes needed to compute the first and second derivatives of the distributions of flow field variables in the axial or radial direction. Since the streamline spacing is irregular, the finite difference scheme takes the variable spacing into account based on linear differencing of the variables between streamlines. For an arbitrary variable, U(r) along a q-o, the radial gradient at radius  $r_i$  is determined with appropriate weighting for variable streamline spacing as

$$\frac{\partial U}{\partial r_{j}} = \frac{r_{j+1} - r_{j}}{r_{j+1} - r_{j-1}} \left[ \frac{U_{j} - U_{j-1}}{r_{j} - r_{j-1}} \right] + \frac{r_{j} - r_{j-1}}{r_{j+1} - r_{j-1}} \left[ \frac{U_{j+1} - U_{j}}{r_{j+1} - r_{j}} \right] \qquad (j = 2...NSTRM-1) \quad (3.5)$$

A one-sided finite difference scheme is needed to compute the radial gradients at the hub and outer casing. Applying a second degree polynomial at streamlines j=1, 2, and 3 along a q-o (Anderson, et. al., 1988) results in the gradient at the hub radius as

$$\frac{\partial U}{\partial r_{j-1}} = \frac{U_2 - U_1}{r_2 - r_1} - \left[ \frac{r_2 - r_1}{r_3 - r_2} \right] \frac{U_3 - U_1}{r_3 - r_1} + \frac{U_2 - U_1}{r_3 - r_1}$$
(3.6)

The corresponding gradient at the casing is

$$\frac{\partial U}{\partial r}_{j=NSTRM} = \frac{U_{NSTRM-1} - U_{NSTRM}}{r_{NSTRM-1} - r_{NSTRM}} - \left[ \frac{r_{NSTRM-1} - r_{NSTRM}}{r_{NSTRM-2} - r_{NSTRM}} \right] \frac{U_{NSTRM-2} - U_{NSTRM}}{r_{NSTRM-2} - r_{NSTRM}} + \frac{U_{NSTRM-1} - U_{NSTRM}}{r_{NSTRM-2} - r_{NSTRM-1}} \right] (3.7)$$

The second derivative of U(r) at radius  $r_i$  is computed as

$$\frac{\partial^2 U}{\partial r^2}_j = \frac{2}{r_{j+1} - r_{j-1}} \left[ \frac{U_{j+1} - U_j}{r_{j+1} - r_j} - \frac{U_j - U_{j-1}}{r_j - r_{j-1}} \right] \qquad (j = 2...NSTRM-1)$$
 (3.8)

Again, a one-sided finite difference scheme is required at the hub and casing, with the results being

$$\frac{\partial^2 U}{\partial r^2}_{j=1} = \frac{2}{r_3 - r_2} \left[ \frac{U_3 - U_1}{r_3 - r_1} \right] - \frac{2}{r_2 - r_1} \left[ \frac{U_2 - U_1}{r_3 - r_2} \right]$$
(3.9)

and

$$\frac{\partial^{2} U}{\partial r^{2}}_{j=NSTRM} = \frac{2}{r_{NSTRM-2} - r_{NSTRM-1}} \left[ \frac{U_{NSTRM-2} - U_{NSTRM}}{r_{NSTRM-2} - r_{NSTRM}} \right] - \frac{2}{r_{NSTRM-1} - r_{NSTRM}} \left[ \frac{U_{NSTRM-1} - U_{NSTRM}}{r_{NSTRM-2} - r_{NSTRM-1}} \right]$$
(3.10)

Axial gradients along a streamline where needed in the solution are computed using Eqns. (3.5) to (3.10), but with z replacing r, index i replacing index j, and NSTNS replacing NSTRM.

Subroutine FLOINT computes the mass flow rate based on the input data at the inlet q-o. The integration technique used is the trapezoidal rule, with integration proceeding from streamline to streamline, starting at the hub and stepping radially outward.

The mass flow rate between adjacent streamlines, j and j-1, using data at the inlet q-o, is computed by

$$\dot{m}_{j} = \left(\frac{\rho_{j} + \rho_{j-1}}{2}\right) \pi \left(r^{2}_{j} - r^{2}_{j-1}\right) \left(\frac{V_{z_{j}} - V_{z_{j-1}}}{2}\right) \qquad (j = 2...NSTRM)$$
 (3.11)

The total mass flow rate, in, for the annulus is the sum of the mass flow rates

between the streamlines.

The fraction of the total mass flow rate between the hub and each streamline is then computed using

fraction<sub>j</sub> = 
$$\frac{\sum_{k=1}^{j} \dot{m}_{k}}{\sum_{k=1}^{NSTRM} \dot{m}_{k}}$$
 (j = 2...NSTRM) (3.12)

The individual fractions of the mass flow rate, therefore, identify the streamlines through the annulus.

Since the flow at the annulus walls is inviscid and adiabatic, and the annulus is blade-free, no global energy transfer into our out of the annulus is possible, although energy may be redistributed within the annulus. As a check on energy conservation, the mass weighted stagnation enthalpy for the annulus is computed using

$$\vec{H} = \frac{1}{\dot{m}} \sum_{j=2}^{NSTRM} \dot{m}_j \left( \frac{H_j + H_{j-1}}{2} \right)$$
 (3.13)

The mass weighted stagnation enthalpy can then be computed for each downstream q-o and the resulting value compared with the inlet value as a check on the flow field calculations.

Subroutine ESTIM estimates, for the initial calculations of the flow field, the static temperature, entropy, density, and streamline radial locations for the q-os downstream

from the inlet for i = 2 to i = NSTNS, where NSTNS is the number of q-os, or computing stations. ESTIM is executed once only at the start of the calculations.

Since the annulus cross section may change from q-o to q-o as shown in Fig. 3.2, the streamline radial locations for the current, or ith, q-o must be estimated using information from the inlet q-o. The streamline radial locations are compute based on fractions of the span at the inlet according to

$$r_{i,j} = \frac{r_{i,j} - r_{i,1}}{r_{1,NSTRM} - r_{1,1}} \left( r_{i,NSTRM} - r_{i,1} \right) + r_{i,1} \left( j = 2...NSTRM - 1, i = 2...NSTNS \right) (3.14)$$

The axial velocity for the ith q-o is estimated using the mass flow rate determined at the inlet. The average density at the inlet q-o and throughout the annulus is given by

$$\bar{\rho} = \frac{1}{NSTRM} \sum_{j=1}^{NSTRM} \rho_j \tag{3.15}$$

Using the annulus area for the ith q-o,  $\bar{\rho}$ , and the total mass flow rate,  $\dot{m}$ , the average axial velocity for the ith q-o is estimated as

$$\bar{V}_{z_i} = \frac{\dot{m}}{\bar{\rho} \pi \left(r^2_{i,NSTRM} - r^2_{i,1}\right)} \qquad (i = 2...NSTNS)$$
(3.16)

The stagnation properties are approximated by simply carrying the values downstream from the inlet station. The tangential velocities are similarly carried downstream. The static temperature, entropy, and density for the ith q-o are determined

using Eqns. (3.4)

Subroutine CURVE calculates the streamline curvature, meridional flow angle, and the axial and radial velocities,  $V_z$  and  $V_r$ , for a q-o. CURVE is the first subroutine executed within a universal iteration for the flow field.

The streamline curvature at the determined streamline intersections with the q-o is computed as

$$\frac{1}{r_{c_j}} = \frac{\left(\frac{\partial^2 r}{\partial z^2}\right)_j}{\left[1 + \left(\frac{\partial r}{\partial z}\right)_j^2\right]^{\frac{3}{2}}} \qquad (j = 1...NSTRM)$$
 (3.17)

where the derivatives of r(z) are determined in DERIV using values of the function at neighboring q-os.

The meridional flow angle of a streamline, j, at a q-o is determined from the finite difference form of Eqn. (2.50), or

$$\phi = \frac{1}{2} \left[ \arctan \left( \frac{r_{i+1} - r_i}{z_{i+1} - z_i} \right) + \arctan \left( \frac{r_i - r_{i-1}}{z_i - z_{i-1}} \right) \right] \qquad (i = 2...NSTNS-1)$$
 (3.18)

At the inlet q-o,  $\phi = 0$  and for the last q-o in the flow field,  $\phi$  is determined using the NSTNS and NSTNS - 1 quasi-orthogonals.

The axial and radial velocities at a q-o are then computed as

$$V_{j} = V_{m_{j}} \cos \phi_{j} \qquad (j = 1...NSTNS)$$

$$V_{r} = V_{m_{j}} \cos \phi_{j} \qquad (3.19)$$

where  $V_m$  is the meridional velocity computed in subroutine VELO.

Subroutine VISCOUS computes the distributions of the viscous body forces,  $E_{\theta}$  and  $E_{z}$ , and the dissipation function,  $\Phi$ , along a q-o. Using the constraints or assumptions concerning the annulus and q-o geometry listed at the beginning of this chapter, the dissipation function given in Eqn. (2.40) becomes

$$\Phi = \mu \left[ \left( \frac{\partial V_z}{\partial r} \right)^2 + \left( \frac{\partial V_{\theta}}{\partial r} - \frac{V_{\theta}}{r} \right)^2 \right]$$
 (3.20)

and the viscous body forces in Eqns. (2.29) and (2.30) are written as

$$E_{\theta} = \frac{1}{r} \frac{\partial}{\partial r} \left[ r \mu \left( \frac{\partial V_{\theta}}{\partial r} - \frac{V_{\theta}}{r} \right) \right]$$

$$E_{z} = \frac{1}{r} \frac{\partial}{\partial r} \left[ r \mu \frac{\partial V_{z}}{\partial r} \right]$$
(3.21)

The dissipation function along a given q-o is then computed as

$$\Phi_{j} = \mu_{j} \left[ \left( \frac{\partial V_{z}}{\partial r} \right)_{j}^{2} + \left( \left( \frac{\partial V_{\theta}}{\partial r} \right)_{j} - \frac{V_{\theta_{j}}}{r_{j}} \right)^{2} \right] \qquad (j = 1...NSTRM)$$
(3.22)

where the gradient terms are computed by Subroutine DERIV and the viscosity is computed using Eqn. (2.51). The viscosity is computed in Subroutine ESTIM for the first global iteration and in Subroutine GRADIENT for subsequent global iterations.

The viscous body forces are computed using

$$E_{\theta_{j}} = \frac{1}{r_{j}} \frac{\partial}{\partial r} \left[ r_{j} \mu_{j} \left( \left( \frac{\partial V_{\theta}}{\partial r} \right)_{j} - \frac{V_{\theta_{j}}}{r_{j}} \right) \right]_{j} \qquad (j = 1...NSTRM)$$

$$E_{z_{j}} = \frac{\partial}{r_{j}} \frac{\partial}{\partial r} \left[ r_{j} \mu_{j} \left( \frac{\partial V_{z}}{\partial r} \right)_{j} \right]_{j} \qquad (3.23)$$

Subroutine GRADIENT calls Subroutine DERIV to determine the meridional gradients of entropy, angular momentum, and stagnation enthalpy at a given q-o, and then updates these flow field variables at that q-o. DERIV is called again to compute the radial gradients needed for integration of the radial equilibrium equation for this q-o in subroutine VELO.

Under the constraints or assumptions listed at the beginning of this chapter, the equations for entropy, angular momentum, and stagnation enthalpy, Eqns. (2.42), (2.46), and (2.45), written for streamline j at the given q-o are:

$$\left(\frac{\partial s}{\partial m}\right)_{j} = \frac{1}{\left(r \rho T V_{m}\right)_{j}} \frac{\partial}{\partial r} \left[r k \frac{\partial T}{\partial r}\right]_{j} + \frac{\Phi_{j}}{\left(\rho T V_{m}\right)_{j}}$$

$$\left(\frac{\partial (r V_{\theta})^{2}}{\partial m}\right)_{j} = 2 r^{2}_{j} \left(\frac{V_{\theta} E_{\theta}}{V_{m} \rho}\right)_{j} \qquad (j = 1...NSTRM)$$

$$\left(\frac{\partial H}{\partial m}\right)_{j} = T_{j} \left(\frac{\partial s}{\partial m}\right)_{j} + \frac{1}{2 r^{2}_{j}} \left(\frac{\partial (r V_{\theta})^{2}}{\partial m}\right)_{j} + \left(\frac{E_{z} \cos \phi}{\rho}\right)_{j}$$

where the radial gradient terms in Eqns. (3.24) are evaluated using DERIV. The heat transfer coefficient, k, is computed according to Eqn. (2.51).

The meridional gradients of entropy, angular momentum, and stagnation enthalpy, computed by Eqns. (3.24), are used to update the flow field variables at the current q-o. The meridional length of each streamline, j, between given adjacent q-os, i-l and i, is computed by

$$\Delta m_{j} = \sqrt{(r_{i,j} - r_{i-1,j})^{2} + (z_{i,j} - z_{i-1,j})^{2}}$$
 (3.25)

The entropy, angular momentum, and stagnation enthalpy are updated along the given streamline for the q-o according to

$$s_{i,j} = s_{i-1,j} + \Delta m_j \left(\frac{\partial s}{\partial m}\right)_{i,j}$$

$$(rV_{\theta})^2_{i,j} = (rV_{\theta})^2_{i-1,j} + \Delta m_j \left(\frac{\partial (rV_{\theta})^2}{\partial m}\right)_{i,j}$$

$$H_{i,j} = H_{i-1,j} + \Delta m_j \left(\frac{\partial H}{\partial m}\right)_{i,j}$$
(3.26)

The change in angular momentum from the previous iteration is relaxed using RF, an arbitrary relaxation factor chosen by the user as

$$(rV_{\theta})^{2}(NEW) = (rV_{\theta})^{2}(OLD) + RF[(rV_{\theta})^{2} - (rV_{\theta})^{2}(OLD)]$$
 (3.27)

The tangential velocity,  $V_0$ , is computed from the updated angular momentum above, and, in turn, the static temperature, pressure, and density are updated using Eqn. (3.18).

The radial gradients of the updated entropy, angular momentum, and stagnation enthalpy along the q-o, required in integration of the radial equilibrium equation, are then computed along the q-o by Subroutine DERIV. The number of the current q-o is sent to GRADIENT in the call list and the main program controls the stepping from q-o to q-o, from i = 2 to i = NSTNS.

Subroutine VELO integrates the radial equilibrium equation to obtain the meridional velocity profile along a given q-o. The resulting profile is used to determine the mass flow rate and the constant of integration involved is then adjusted as necessary to

achieve mass continuity. Once mass continuity is satisfied, the main program steps the computations to the next q-o.

Using the assumptions of a blade - free annulus and radially directed quasiorthogonals, the radial equilibrium equation, Eqn. (2.24), may be rearranged to give

$$\frac{\partial V_m^2}{\partial r} = B - A V_m^2 \tag{3.28}$$

where

$$B = 2 \left[ \frac{\partial H}{\partial r} - T \frac{\partial s}{\partial r} - \frac{1}{2r^2} \frac{\partial (rV_0)^2}{\partial r} - E_m \sin \phi \right]$$
 (3.29)

and

$$-A = 2\left[\frac{\cos\phi}{r_c} + \frac{\sin\phi}{V_m} \frac{\partial V_m}{\partial m}\right]$$
 (3.30)

where A and B are functions of radius, r, along the q-o.

Equation (3.28) is a linear, first order, ordinary differential equation and may be integrated by using a suitable integrating factor.

Multiplying Eqn. (3.28) by an integrating factor, s, and rearranging yields

$$s \frac{\partial V_m^2}{\partial r} + s A V_m^2 = s B \tag{3.31}$$

For the left - hand side of Eqn. (3.31) to be an exact differential, we require

$$\frac{\partial (s V_m^2)}{\partial r} = s \frac{\partial V_m^2}{\partial r} + V_m^2 \frac{\partial s}{\partial r}$$
 (3.32)

Comparing Eqns. (3.31) and (3.32), it can be seen that

$$\frac{\partial s}{\partial r} = sA \tag{3.33}$$

from which

$$s = e^{\int A dr} ag{3.34}$$

where a constant of integration has been omitted for simplicity.

Substituting Eqn. (3.34) into Eqn. (3.31) then yields

$$\frac{\partial}{\partial r} \left[ e^{\int A dr} V_m^2 \right] = B e^{\int A dr} \tag{3.35}$$

Equation (3.35) may now be integrated along a q-o from a point  $r_i$  where  $V_m = V_{mi}$  to obtain

$$V_m^2 = e^{\int -Adr} \int_{r_1} \left[ B e^{\int Adr} \right] dr + V_{m_1}^2 e^{\int -Adr}$$
 (3.36)

For a short distance  $r_i$  to r, A and B can be approximated as average values  $\overline{A}$  and  $\overline{B}$ . Therefore, Eqn. (3.36) becomes

$$V_m^2 = e^{-\vec{A}(r-r_1)} \vec{B} \int_{r_1}^r \left[ e^{\vec{A}(r-r_1)} \right] dr + V_{m_1}^2 e^{-\vec{A}(r-r_1)}$$
 (3.37)

Evaluating the integral in Eqn. (3.37) and simplifying yields

$$V_m^2 = \frac{\bar{B}}{\bar{A}} \left[ 1.0 - e^{-\bar{A}(r-r_1)} \right] + V_{m_1}^2 e^{-\bar{A}(r-r_1)}$$
 (3.38)

If  $\overline{A}=0$ , Eqn. (3.38) is indeterminate. Applying L'Hopitals rule to evaluate in the limit as  $\overline{A}$  goes to zero then gives

$$V_m^2 = \overline{B}(r - r_1) + V_{m_1}^2 \tag{3.39}$$

The forms of Eqns. (3.38) and (3.39) used to integrate the radial equilibrium equation from the middle streamline to the tip are

$$V_{m_{j}}^{2} = \frac{\bar{B}_{j}}{\bar{A}_{j}} \left[ 1.0 - e^{-\bar{A}_{j}(r_{j} - r_{j-1})} \right] + V_{m_{j-1}}^{2} e^{-\bar{A}_{j}(r_{j} - r_{j-1})}$$

$$V_{m_{j}}^{2} = \bar{B}_{j} \left[ r_{j} - r_{j-1} \right] + V_{m_{j-1}}^{2} \qquad (j = j_{mid+1}...NSTRM)$$
(3.40)

and for integration from the middle streamline to the hub

$$V_{m_{j}}^{2} = \frac{\overline{B}_{j}}{\overline{A}_{j}} \left[ 1.0 - e^{-\overline{A}_{j}(r_{j} - r_{j+1})} \right] + V_{m_{j+1}}^{2} e^{-\overline{A}_{j}(r_{j} - r_{j+1})}$$

$$V_{m_{j}}^{2} = \overline{B}_{j}[r_{j} - r_{j+1}] + V_{m_{j+1}}^{2} \qquad (j = j_{mid-1}...1)$$
(3.41)

where  $V_m^2$  at  $j_{mid}$  is the meridional velocity (VMID) from the previous iteration or the initial solution estimate.

The change in the velocity profile from a previous local iteration is relaxed using the relaxation factor RF as

$$V_m^2(NEW) = V_m^2(OLD) + RF[V_m^2 - V_m^2(OLD)]$$
 (3.42)

The integration of the radial equilibrium equation may return negative values for the square of the meridional velocity. If this occurs, the square of the meridional velocity is set to 1.0

The mass flow rate and mass weighted stagnation enthalpy are then calculated using Eqns. (3.11) to (3.13) as described for subroutine FLOINT. Mass continuity is checked by comparing the difference between the (local) and the (inlet) with a user chosen

tolerance. If continuity is not satisfied, a secant method routine (Chapra and Canale, 1988) is used to find a new value of  $V_m^2$  at  $j_{mid}$  and the radial equilibrium equation is reintegrated using the new constant of integration. A local iteration is designated as one integration of the radial equilibrium equation and check of mass continuity.

Subroutine RADIAL adjusts the streamline radial locations to match the required fractions of the mass flow rate at the current q-o. The meridional velocities which correspond to the new streamline radii are then interpolated from the velocity profile using Subroutine INTERP.

The change in radii between iterations is damped using a relaxation factor (Wilkinson, 1969-70). The optimum relaxation factor as determined by Wilkinson is

$$RF = \frac{1}{1 + \frac{5}{24} \left( 1 - M_{\rm m}^2 \right) \left( \frac{SPAN}{\Delta z} \right)}$$
 (3.43)

where  $M_m$  is the mean Mach number on a q-o, span is the distance between the outer casing and the hub, and  $\Delta z$  is the quasi-orthogonal spacing. Thus, the change in streamline radius at a given q-o is damped according to

$$r(NEW) = r(OLD) + RF[r - r(OLD)]$$
 (3.44)

where r is the radius interpolated from the velocity profile.

Subroutine INTERP is an interpolation routine using second degree Lagrange interpolating polynomials (Chapra and Canale, 1988). XDATA and YDATA are arrays

of known values of NDATA points each, i.e. YDATA = f (XDATA). Subroutine INTERP computes the ordinate values, YOUT, corresponding to the abscissa points, XIN.

INTERP checks first to ensure that all XIN data points lie within the upper and lower bounds of XDATA and then compares each XIN data point sequentially with the XDATA values to find bracketing values. The interpolation result is then

$$YOUT = \frac{[XIN - XDATA(k+1)][XIN - XDATA(k+2)]}{[XDATA(k) - XDATA(k)][XDATA(k) - XDATA(k+2)]}YDATA(k)$$

$$+ \frac{[XIN - XDATA(k)][XIN - XDATA(k+2)]}{[XDATA(k+1) - XDATA(k)][XDATA(k+1) - XDATA(k+2)]}YDATA(k+1)$$

$$+ \frac{[XIN - XDATA(k)][XIN - XDATA(k+1)]}{[XDATA(k+2) - XDATA(k+1)]}YDATA(k+2)$$

Subroutines CONVER1 and CONVER2 check the convergence of the meridional velocities and streamline radii through the passage. At each streamline and q-o intersection, the change in velocity and radial location is compared with user chosen tolerances as

$$\frac{\left|\frac{V_{m}(OLD) - V_{m}}{V_{m}}\right| \leq tolerance (velocity)}{\left|\frac{r(OLD) - r}{r}\right| \leq tolerance (radial)}$$
(3.46)

If convergence is not attained, the old meridional velocity and radial location take the

values of the new velocity and radial location.

The main program calls Subroutine OUTPUT if both the meridional velocities and the streamline radial locations have converged or if the maximum number of iterations desired by the user has been exceeded. If the flow field has not converged, a new iteration is started.

#### 4. EXAMPLE SOLUTIONS

Example Problem 1 is for axial flow through an annular passage. If no tangential velocity profile is included in the input, integration of the radial equilibrium equation, Eqns. (3.2) and (3.3), at the inlet q-o results in a constant axial velocity profile. Because of this velocity condition at the inlet, the viscous body forces, Eqns. (3.23) and the dissipation function, Eqn. (3.20), are all zero and the static temperature profile, Eqn. (3.4), is constant across the inlet. Thus, the meridional gradients of entropy, angular momentum, and stagnation enthalpy in Eqns. (3.24) are all zero.

For constant radius hub and casing shape, initialization of the flow field by Subroutine ESTIM will result in carrying the inlet axial velocity profile and streamline locations to the downstream q-os. Integration of the radial equilibrium equation using Eqns. (3.40) and (3.41) simply returns the constant axial velocity since the streamline curvature and meridional flow angle are zero. Because no changes occur, the program will converge for any value of viscosity or convergence tolerance input by the user.

An annular passage with varying hub and casing shape forces the estimation of the flow field for q-os downstream from the inlet to change. For a converging passage, the downstream axial velocity profiles are initialized as constant values from hub to tip; however, the velocity values and the streamline radial locations vary from q-o to q-o. The viscous body forces, dissipation function, and meridional gradients of entropy, angular momentum, and stagnation enthalpy remain zero. Integration of the radial equilibrium equation for this case results in a new meridional velocity profile. Thus, the effect of the

varying endwall geometry propagates through the system of governing equations.

The program was run for the case of a converging nozzle with no tangential velocity input. The hub and casing profiles formed a converging passage with smoothly varying first and second derivatives. The hub and casing were symmetric about a centerline of the passage. Convergence was attained after 3 global and 2 universal iterations.

The streamline and quasi-orthogonal locations and the axial, radial, and meridional velocity profiles from the converged solution are shown in Fig. 4.1. As can be seen in Fig. 4.1 the flow velocities are not symmetric about the centerline, although the passage is symmetric. This asymmetry occurs because of the differing areas between streamlines. The full program output is contained in Appendix D.

Example Problem 2 is for axial flow with swirl through a straight annulus. This second test case was run using a constant radius hub and casing shape. The tangential velocity profile at the inlet formed a free vortex profile. The program converged for this case after 2 global and 2 universal iterations. Figure 4.2 shows the streamline and quasi-orthogonal locations and the axial, radial, meridional, and tangential velocity profiles for this test case. The calculations were carried out for 21 streamlines, however, results are shown for every fifth streamline only. The program output is contained in Appendix D.

Tangential shear stresses on the radially inward and outward faces of the streamtubes due to the  $\theta$  direction velocities should cause the free vortex profile to shift towards a forced vortex profile. The tangential velocity field shown n Fig. 4.2 shows only

a small change in velocities without the expected shift towards a forced vortex profile (Gallimore, 1985). The axial velocity profiles remain essentially constant throughout the flow field with no streamline radial location shifts.

Cuvature calculations are unstable even in inviscid flows and adding viscosity decreases stability even more. It is thought at this time that calculations are not being carried far enough downstream for the flow to shift to the forced vortex profile. Work is continuing in this direction at this time (Grabowska, 1994).

PROGRAM CALCULATION SUMMARY

GLOBAL ITERATIONS TO REACH CONVERGENCE: UNIVERSAL ITERATIONS TO CONVERGENCE:

THE MASS FLOW RATE FOR THE ANNULUS: 0.490 slug/sec

10.500 10.312 10.122 10.122 9.736 9.539 9.137 8.930 8.930		2555 2555 2555 2555 2555 2555 2555 255	-2.4. -1.54. -1.54. -0.03. -0.	255.29 255.24 255.24 255.24 255.19 255.20 255.20 255.23 255.31
10.510 10.320 10.128 9.738 9.539 9.539 8.924 8.924	5.50	2552 2552 2552 2552 2552 2552 2552 255	-18.33 -15.01 -11.50 -7.84 -4.02 3.64 11.28 11.28 14.92	252.93 252.93 252.98 252.86 252.88 252.88 252.98 252.95 252.95
10.573 10.167 10.167 9.961 9.52 9.540 9.325 9.107 8.885 8.659	5.00	233.74 235.38 236.77 238.79 238.58 238.79 237.91 235.81 235.81	1 1 1 1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	2338.88 238.88 238.88 238.82 238.32 238.38 238.81 238.93 238.93
10.722 10.494 10.261 10.025 10.025 9.541 9.541 9.294 8.392 8.316	4.50	202.11 202.11 202.11 205.96 211.07 211.79 201.10 205.96 205.96 197.84	-75.99 -63.60 -49.65 -17.53 -17.53 -0.18 17.25 -0.18 -	211.89 211.88 211.82 211.82 211.79 211.79 211.94
10.960 10.687 10.125 10.125 9.581 9.241 9.241 8.341 8.341 8.341 8.341	4.00	159.05 165.27 170.95 178.65 179.66 179.66 179.61 170.61 165.06	-83.75 -70.66 -35.43 -19.15 -1	179, 75 179, 75 179, 75 179, 69 179, 66 179, 67 179, 75 179, 75
11. 250 10.922 10.242 9.537 9.178 8.619 8.103	3.50	1336.07 136.09 136.09 136.09 136.09 136.19 136.10 136.10	-75.89 -63.62 -63.62 -49.41 -16.06 1.91 19.65 51.41 51.41 51.41 51.41	150.59 150.59 150.55 150.55 150.54 150.57 150.62
11.54 10.756 10.352 9.528 9.528 8.695 7.867	ARE: 50 3.00	113.11 118.22 122.46 125.56 127.73 126.79 126.79 121.50 117.60	2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00	127.79 127.78 127.78 127.77 127.76 127.76 127.76 127.79 127.78
ARE: 11.333 11.333 10.430 9.974 9.9515 9.054 8.594 8.594 7.677	(inches) 2.5(	ARE: 105.06 107.97 110.15 111.37 112.41 111.96 1109.48 107.47	ARE: -40.08 -31.40 -12.64 -12.64 -5.56 -5.56 -7.56 10.48 18.17 25.70 33.10	Bec) ARE: 1112.45 1112.45 1112.45 1112.46 1112.46 1112.45 1112.46
(inche) 11.927 11.927 10.946 10.978 9.992 9.018 8.531 8.531 7.558	ATIONS 0 2	(ft/aec) 1 100.76 100.76 100.75 102.37 102.97 102.99 102.59 102.17	(ft/8ec) -21.33 -16.19 -11.35 -2.58 -2.59 -3.32 9.17 13.08	EBS (FE) (103.00 (FE) (FE) (FE) (FE) (FE) (FE) (FE) (FE)
LOCATIONS 11.990 11.493 10.495 10.495 9.999 9.002 8.504 7.508	ECTION . 00	LOCITIES 100.12 100.13 100.34 100.36 100.38 100.37 100.22 100.22	VELOCITIES -7.27 -5.43 -3.76 -2.23 -0.81 0.52 1.81 3.10 4.41	AL VELOCITY 100.38 100.38 100.38 100.38 100.38 100.38 100.38
RADIAL 12.000 11.500 11.500 10.500 9.500 9.500 8.500 7.500	9-0 Z DI	AXIAL VEL 100.00 100.00 100.00 100.00 100.00 100.00 100.00	ADIA 0.00000000000000000000000000000000000	MER IDIONA 1000.00 1000.00 1000.00 1000.00 1000.00 1000.00 1000.00 1000.00
H1000000000000000000000000000000000000	# 1	111 101 100 100 100 100 100 100 100 100	11 10 10 10 10 10 10 10 10 10 10 10 10 1	111 100 100 46 74 110 110 110 110 110 110 110 110 110 11

PROGRAM CALCULATION SUMMARY

GLOBAL ITERATIONS TO REACH CONVERGENCE:
UNIVERSAL ITERATIONS TO CONVERGENCE:
ALL DIMENSIONS IN ft, sec, lbf, R UNLESS NOTED

THE MASS FLOW RATE FOR THE ANNULUS: 0.3301 slug/sec

	100.00 100.00 100.00 100.00		100.00 100.00 100.00 100.00	
10.000 9.000 8.000 7.000 6.000	100.00 100.00 100.00 100.00	000000	100.00 100.00 100.00 100.00	7.20 8.00 8.97 10.28 12.03
10.000 9.000 8.000 7.000 6.000	100.00 100.00 100.00 100.00	00.00	100.00 100.00 100.00 100.00	7.20 8.00 8.97 10.28 12.03
10.000 9.000 8.000 7.000 6.000	100.00 100.00 100.00 100.00	00.00	100.00 100.00 100.00 100.00	7.20 8.00 8.97 10.27 12.03
10.000 9.000 8.000 7.000 6.000	100.00 100.00 100.00 100.00	00000	100.00 100.00 100.00 100.00	7.20 8.00 8.97 10.26 12.03
10.000 9.000 8.000 7.000 6.000	00.00	00000	100.00 100.00 100.00 100.00	7.20 8.00 8.98 10.26 12.02
10.000 9.000 8.000 7.000 6.000	88888	0.00 0.00 0.00 0.00	00.001 00.001 00.001 00.001	7.20 8.00 8.98 10.25 12.02
10.000 9.000 8.000 7.000 6.000	100000000000000000000000000000000000000	00000	000000	7.20 8.00 8.98 10.24 12.02
10.000 9.000 8.000 7.000 6.000	ARE: 100.0 100.0 100.0 100.0 100.0	sec) ARE: 0.00 0.00 0.00 0.00	(ft/sec) A .00 100. .00 100. .00 100. .00 100.	c) ARE: 7.20 8.00 8.99 10.24 12.01
S (inches) 10.000 10 9.000 9 8.000 7 7.000 7 6.000 6	S (ft/sec) 100.00 100.00 100.00 100.00	ES (ft/8 0.00 0.00 0.00 0.00 0.00	TIES 100 100 100 100 100	S (ft/sec) 7.20 8.00 8.99 10.24
10.000 10. 8.000 9. 8.000 8. 7.000 7. 6.000 6.	XIAL VELOCITIES (00.00 100.00 (00.00 100.00 (00.00 100.00 (00.00 100.00 99.99 100.00	VELOCITI 0.00 -0.00 -0.00 -0.00 0.00	NAL VELOCI 100.00 100.00 100.00 100.00	ELOCITIE 7.20 8.00 8.99 10.26 12.00
THE RADIAL 21 10.000 16 9.000 6 7.000 1 6.000 1 6.000	*	RADIAL 0.00 0.00 0.00 0.00	MERIDIONAL 100.00 100.00 100.00 100.00 99.99	THETA VEL 7.20 8.00 9.00 10.28
五 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	111 111 111 111	7HE 21 16 11 6 11 11 11 11 11	116 11 11 6 6	理 21 11 6 11

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### APPENDIX A. DISTRIBUTED BLADE BODY FORCES

The component momentum equations, Eqns. (2.10) – (2.12), contain the distributed blade body force terms  $f_n$ ,  $f_\theta$ , and  $f_m$ . These terms are functions of the blade geometry as described below. Wennerstrom (1974) defined the distributed blade body force terms as functions of both geometry and the entropy generated by flow over the blades.

Figure A2 shows a point on an arbitrary blade with lean in the intrinsic coordinate system,  $(n, \theta, m)$ , at a distance, r, from the axis of the turbomachine. The quasi-orthogonal,  $\vec{q}$ , lies in the meridional (m-n) plane at an angle  $(\phi + \gamma)$  from the n direction (see also Fig. 2.4). The blade, which is not shown, is described by the mean camber surface. The unit vector,  $\hat{B}$ , is tangent to the blade surface at an angle  $\epsilon$  from  $\vec{q}$ , and lies in the  $(q-\theta)$  plane.  $\hat{s}$  is a unit vector tangent to the blade surface at an angle  $\hat{b}$  from  $\hat{e}_m$  and lies in the  $(\theta-m)$  plane. The blade body force due to pressure differences across the pressure and suction sides of the blade,  $\hat{f}_p$ , is normal to the blade surface.

From Fig. A2, the following unit vectors in the blade surface tangent plane may be written:

$$\hat{S} = \cos\beta \,\hat{e}_m + \sin\beta \,\hat{e}_\theta$$

$$\hat{B} = \csc \, \sin(\phi + \gamma) \,\hat{e}_m - \sin\epsilon \,\hat{e}_\theta + \csc \, \cos(\phi + \gamma) \,\hat{e}_n$$
(A1)

The unit vector in the direction of  $f_p$  is found from the cross product,  $\hat{\mathbf{B}} \times \$$  giving

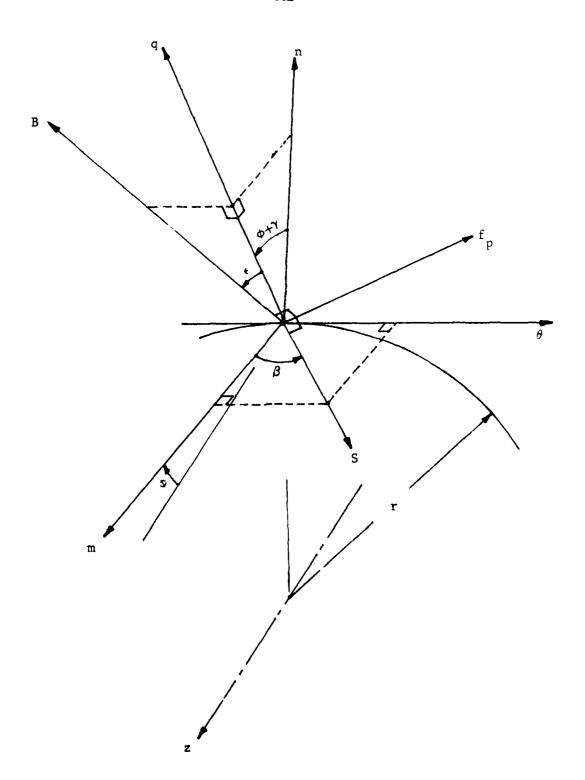


Figure A1. Blade force geometry

$$\frac{\vec{f}_{p}}{\left|\vec{f}_{p}\right|} = \left[-\sin\beta \csc\cos(\phi + \gamma)\right] \hat{e}_{m} + \left[\cos\beta \csc\cos(\phi + \gamma)\right] \hat{e}_{\theta} + \left[\sin\beta \csc\sin(\phi + \gamma) + \cos\beta \sin\epsilon\right] \hat{e}_{n}$$
(A2)

This differs from Wennerstrom's (1974) form of the equation due to an error in the cross product.

The distributed blade body forces for the  $(n, \theta, m)$  coordinate directions are determined by separating the components of  $f_p$  to give

$$f_{n} = f_{p} [\sin \beta \cos \epsilon \sin(\phi + \gamma) + \cos \beta \sin \epsilon]$$

$$f_{\theta} = f_{p} [\cos \beta \cos \epsilon \cos(\phi + \gamma)]$$

$$f_{m} = f_{p} [\sin \beta \cos \epsilon \cos(\phi + \gamma)]$$
(A3)

The tangential blade body force may be determined by rearranging the tangential momentum equation, Eqn. (2.11), to give

$$f_0 = \frac{V_m}{r} \frac{\partial}{\partial m} \left( r \, V_m \, \tan \beta \right) \tag{A4}$$

The magnitude of  $f_p$  can then be found from the tangential component equation in Eqn. (A3) and the results substituted into the normal and meridional component equations, yielding

## APPENDIX B. GOVERNING EQUATIONS IN CYLINDRICAL COORDINATES

The governing equations for streamline curvature throughflow analysis (see Section 2.6) may be written for cylindrical streamsurfaces with streamline coordinate, m, corresponding to the axial coordinate, z, the normal coordinate, n, to the radius, r, and with the angle  $\phi = 0$  and  $r_c = \infty$ . Thus, in cylindrical coordinates, we obtain,

Viscous Body Forces, (from Eqn. (2.13))

$$E_{r} = 0$$

$$E_{\theta} = \frac{1}{r} \frac{\partial}{\partial r} \left[ r \mu \left( \frac{\partial V_{\theta}}{\partial r} - \frac{V_{\theta}}{r} \right) \right]$$

$$E_{z} = \frac{1}{r} \frac{\partial}{\partial r} \left[ r \mu \frac{\partial V_{z}}{\partial r} \right]$$
(B1)

Entropy/Energy Equation, (from Eqn. (2.41))

$$\frac{\partial s}{\partial z} = \frac{1}{\rho T V_z} \frac{\partial}{\partial r} \left( r k \frac{\partial T}{\partial r} \right) + \frac{\Phi}{\rho T V_z} + \frac{\partial S_e}{\partial z}$$
 (B2)

where the dissipation function,  $\Phi$ , from Eqn. (2.40) is written as

$$\Phi = \mu \left\{ \left[ \frac{\partial V_{\theta}}{\partial r} - \frac{V_{\theta}}{r} \right]^2 + \left[ \frac{\partial V_z}{\partial r} \right]^2 \right\}$$
 (B3)

Meridional Momentum/Enthalpy Equation, (from Eqn. (2.45))

$$\frac{\partial H}{\partial z} = T \frac{\partial s}{\partial z} + \frac{1}{2r^2} \frac{\partial (rV_{\theta})^2}{\partial z} + E_z + f_z$$
 (B4)

Angular Momentum, (from Eqn. (2.46))

$$\frac{1}{2r^2} \frac{\partial (rV_{\theta})^2}{\partial z} = \frac{V_{\theta}}{V_{\tau}} (E_{\theta} + f_{\theta})$$
 (B5)

Radial Equilibrium, (from Eqn. (2.24))

$$V_{z} \frac{\partial V_{z}}{\partial r} = \frac{\partial H}{\partial r} - T \frac{\partial s}{\partial r} - \frac{1}{2r^{2}} \frac{\partial (rV_{\theta})^{2}}{\partial r} - f_{r}$$
 (B6)

#### APPENDIX C. COMPUTER PROGRAM LISTING

The main program and associated subroutines contained in Appendix C are roughly in the order in which they are executed (See Fig. 3.1). Each routine contains commment lines which describe the input and output variables required for operation as well as describing the purpose of each section of code.

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```
CALCULATE THE CHRAVTURE AND THE FLOW ANGLE FOR THE FLOW FIELD
PRINT*, 'CALLING CURVE'
THIS ROUTINE READS THE INPUT POR THE ANNULUS PROGRAM. THE STRGMATION
THE AND PRESSIRE ARE ASSUMED TO BE CONSTANT ACROSS THE INLET AREA.

PRINT*, 'CALLING INPUT'
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   TAMPEZOIDAL RULE AND CAL/CULAREA MERGED STAGARION ENTALLY FOR THE STAGARIONS A MERGED STAGARION ENTALLY FOR THE TAMPEZOIDAL RULE AND CAL/CULAREA MERS AVERGED STAGARION ENTALLY FOR THE STAGARION FO
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    POR THE FIRST GLOBAL ITERATION, THE CONDITIONS AT THE INLET q-o ARE USED TO APPROXIANTE THE FLOW CONDITIONS AT THE NEXT (DOMNSTREAM) q-0.

PRINT*, 'CALLING ESTIN'
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   • CALCULATE E2 AND ETHETA (VISCOUS BODY FORCES) AND
• THE DISSIBATION FUNCTION.

PRINT*, 'CALLING VISCOUS'
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     THE GRADIENT SURFOUTINE CALCULATES THE ENTROPY ENTHALPY, AND
VELOCATTY GRADIENTS AT THE ITH q-o AS WELL AS UPDATES VALUES FOR THE
FLOW FIELD VARIABLES AT THE ITH q-o.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             CALCULATE EAND ETHERA (VISCOUS BODY FORCES) AND
                                                                                                                                                                                                                                                       INPUT(CURV, DISSIP, DMHIM, ENTHAL, ENTROP, ETHETA, EZ, HASTAG, HTOCEF, MOELTH, NID, MUT, NSTNS, NSTRM, PHI, PRESS, PSTMG, RADIUS, MDELTA, RHO, RVEL, TEMP, TSTMG, VELM, VELTOT, VTMETA, WHIEL, ZDELTA, ZLOC, ZVEL)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            DO 10 1=2.NSTNS
CALL ESTIN (ENTHAL, ENTROP, HTCOEP, I, MASTOT, NUT,
NSTNA, NSTRM, PRESS, RADIUS, RDELTA, RHO, RVEL, TEMP,
TSTNG, VELM, VELNOT, VTHETN, ZVEL)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     NSTRM,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           CALL FLOINT (HOSUM, HSTAG, MASTOT, MFRAC, NSTRM, RADIUS, RHO, ZVEL)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    DO 40 1=2,NSTNS
CALL VISCOUS(DISSIP, ETHETA, EZ, I, MUT, NSTNS,
L RADIUS, RDELTA, VELM, VTHETA, 2VEL)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       DO 30 1=2,NSTNS
CALL CURVE(CURV, I, NSTNS, NSTRM, PHI, RADIUS,
CARTINUE
CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              PRINT*, 'CALLING PLOINT'
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  PLAG = 0
COUNT = COUNT + 1
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      CONTINUE
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                CONTROL CONTROLS THE CONSTRUCT, NAMES ARE SELF - EVIDENT
CONTROL CONTROL VARIABLES
LILITY SETS THE LEAST WARREN OF GLOBAL TTERATIONS ALLOHED
HINTS SETS THE WAS CONSERVATION CALCS
TOLM - TOLERANCE FOR CHANGE OF VELOCITY (GLOBAL ITERATIONS)
TOLM - TOLERANCE FOR CHANGE OF VELOCITY (GLOBAL ITERATIONS)
TOLM - TOLERANCE FOR CHANGE OF VELOCITY (GLOBAL ITERATIONS)
RELAXT - RELAXITION FACTOR FOR CHANGE IN MEXIDIOLAL VELOCITY
RELAXT - RELAXITION FACTOR FOR CHANGE IN TANGENTAL VELOCITY
COUNT EXPLAINED BELOW - LE EXPLAINED IN input. (COUNT SYPLAINED IN LINIT, NELLY INCO.)
COMMON / CORTELLY COUNT, LLINIT, LD, MILNIT, NSTEP
COMMON / COPTELLY RELAXY, FELAXY, TOLM, TOLK, TOLR
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               DOUBLE PRECISION CP. CURVISIA.2001. DHODM (11, 200). DHODG (11, 200). DESMISIA.2001. DHODM (11, 200). DHODG (11, 200). DESMISIA.2001. DHODM (11, 200). DTD (12, 200). DESMISIA.2001. DHODM (11, 200). DHODG (11, 200). RETHERA (11, 200). RETHERA (11, 200). RETHERA (11, 200). NASTOR, RETHERA (11, 200). PRI PRECISIA.200). RETHERA (11, 200). RELAXY. RELAXY.
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PI UNITS - FALDLINS
PLANDINS - ALDLINS
PLANDINS - ALDLINS
PLANDINS - ALDLINS
PLANDINS - PLANDINS
PLANDINS - PLANDI
                • WRITE PERMANENT CODE IN UPPER CASE, temporary code in lower case
.use • POR PERMANENT COMBENTS, c for temporary comments
.use • POR PERMANENT COMBENTS.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       Ħ
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             INTEGER COUNT, FLAG, GIT, I, LLINIT, LP, MLINIT, NID, NSTEP, NSTNS, NSTRM, UIT
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            COUNT IS A GLOBAL ITERATION COUNTER (NUMBER OF TIMES THROUGH 'WHOLE FLOM FIELD WITH RADIAL LOCATIONS HELD CONSTANT)
WINT IS THE UNIVERSAL ITERATION COUNTER (CHANGE OF RADII)
INPUT AND FLOINT ARE ONLY CALLED ONCE.
COUNT : 1
UNIT : 1
                                                                                                                                   STREALLINE CURVATURE ANALYSIS - WHIRL VERSION:
VARIABLE ENDIALL GEOMETRY
WHIRL IS INCLUDED
RADIAL COMPATING STATIONS
BLADE FREE SPACE
                                                      main.f
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PRINT OUT THE REGULTS

WOTE THAT HE WRITE STATEMENTS USE IMPLIED DO LOOPS

WOTE THAT OUT THE WRITE STATEMENTS USE IMPLIED DO LOOPS
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FLAG IS RESET TO ZERO FOR RADIUS CONVERGENCE CHECK.

100 FLAG = 0
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         IFFLAG . BQ. 1) THEN
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   CHECK STREAMLINE RADIAL LOCATION CONVERGENCE WITH CONVERS PRINT*, 'CALLING CONVERS'
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    FRINT.

FAILED RADIAL CONVERGENCE.

PRINT.

PR
                                                                                                                                                                                                                                                                                                                                                                       PRINT: 'CALLING RADIAL'
DO 90 1=2,NGTNB.
CALL RADIAL!I, NFRAC, NSTNS, NSTRM, RADIUS, RAINEM,
A. RDELTA, TEMP, VELM, VELNEW, ZDELTA)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  150 PRINT*, 'CALLING OUTPUT'
PRINT*, ''
PRINT*, ''
PRINT*, ''
PRINT*, ''THE GLOBAL ITERATION COUNT IS:', COUNT
PRINT*, 'THE UNIVERSAL ITERATION COUNT IS:', UNIT
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              CALL CONVERZ (FLAG, NSTRM, NSTNS, RADIUS, RADNEW, VELM, VELNEW)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        8
COMPUTE THE TRANS POR THE SUBGUTINE ARE CONSTANT POR THIS INTEGRALONS

THE INPUT TERMS POR THE SUBGUTINE ARE CONSTANT POR THIS INTEGRALION

FRIPT. 'CALLING VELO'

DO 60 1=2, NSTNE, DEDO, DEDO, DANIM, DANID, HOSUM, HSTAC, I,

**AMSTOT, MFRAC, MID, NSTRM, PHI, RADIUS, RHO, TEAP, VELM)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  CHECK MADIAL CONTREDUE: IF THE PIELD HAS NOT COVERED. THE PROCAMA STARTS ANOTHER TETALTION. NOTE THE COTO STATEMENT, IT IS THE STARTS ANOTHER TETALTION. NOTE THE OTHER TETALTH. IT IS THE THE TETALTION CONTRETE IS INCREMENTED BY ONE AND PLAG IS RESET TO ZERO THE ITERATION CONTRET IS INCREMENTED BY ONE AND PLAG IS RESET TO ZERO THE TREATION CONTRET TO STATEMENT TO STAT
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                VELNEM (J. 1) = VELM (J. 1)
IF VELMEM (J. 1) = LE. 0,000) PRINT*, 'VELNEM ERROR FROM VELO'
CONTINUE
CONTINUE
CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       ITERATION NUMBER WITHING LIMITS, CHECK FOR CONVERGENCE (FLAG).
IFFLAG. 20. 117HEN
PRINT:
PRIN
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               CHECK THE MIN AND MAX LIMITS FOR 8 OF ITERATIONS, BRANCH AS NEEDED.
IP (COURT LT. LLIMIT) THEN
PRINT. 'FORCED ITERATION REQUIRED'
PRINTS.
                                                                                                                     CALL GRADIBATION-DO, DISSIP, DSDO, DVADM, DWADM, TANDER, LOBODD, BATABL, ERRORD, ETHERA, EST, MSTAG, WIT, MSTAG, WSTAG, W
                                                                                                                                                                                                                                                                                                                                                                                                                                                       COPY LAST ITERATION VELM TO OLDWH FOR VELOCITY CONVERGENCE CHECK IN SUBROUTINE CONVERI.

DO $4 1=2, NETTEN

DO $2.1 NETTEN

OLDWH(3,1) = VELM(3,1)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           • MAKE NEWEST VELM TO VELNEW POR CONVERGENCE CHECK IN CONVERI
DO 64 1=2, NSTNS
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     IP(COUNT. GE. NLIMIT) THEN
PRINT: 'ITERATION LIMIT: PROGRAM INTERUPT'
GOTO 150
BADIP
BADIF
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         CALL CONVERI(PLAG, NSTRM, NSTNS, RADIUS, RADNEM, & VELM, VELMEW)
PRINT*, 'CALLING GRADIENT'
                                                                                DO 50 I=2, NSTNS
                                                                                                                                                                                                                                                                                                                            CONTINUE
                                                                                                                                                                                                                                                                                                                                      9
```

```
CALL SUBROUTHE INLET, WHICH COMPUTES ALL THE VARIABLES AND RADIAL
CRADIEATY POR THE INLET q-0.
CAL INLET (CURV. DISSIP, DANIAN, DANIAN, DATAL, ENTROP.
L. PHI, PRESS, HATGAE, HATGAE, ANDLUS, RADIUS, RADIUS, RADIUS, TOMPIN, NETRA, L. PENPIN, TSTAG, VELM, VELTOT, VMID, VTHETA, WHIRL, ZDELTA, ELLOC, ZUEL,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          ECHO THE INPUT VAILABLES TO THE OUTPUT PAIR A REQUIRED BY LP
LP VALUES ARE LISTED AT THE LETT OF THE OUTPUT FILE NARES.
USE LP = 20 TO HAVE FILES WITTER POR ALL SUBROUTINES.
THESE OUTPUT PILES WILL BE USED TO STORE THE DATA FOR DEBLOCAINE.
OUTPUT: DAT - INPUT AND PLOW INTEGRATION DATA - WRITTEN ONCE.
OUTPUT: DAT - SUBROUTINE CHANC.
OUTPUT: DAT - SUBROUTINE CHANC.
OUTPUT: DAT - SUBROUTINE GRADIENT
OUTPUTS: DAT - SUBROUTINE GRADIENT
OUTPUTS: DAT - SUBROUTINE RADIAL AND INTERP
1 THERATION
1 OUTPUTS: DAT - SUBROUTINE RADIAL AND INTERP
1 THERATION
1 OUTPUTS: DAT - SUBROUTINE CONVERGI & 2
1
                                                                                                                                                                                                                                                                                                                                                                                                                                                          READ(10.*) LP. LLINIT, MLINIT, RELAXV, RELAXW, TOLM, TOLV, TOLR REAL(10.*) PRESSIN. TEMPT. MIXCO
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    DO 20 1=2.NSTNS
READ(10,*) RADIUS(NSTRM,1), RADIUS(1,1), ZLOC(1)
PRINT*, RADIUS(NSTRM,1), RADIUS(1,1), ZLOC(1)
CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                      PRINT*, 'OPENING INPUT FILE AND READING DATA'
OPEN(10, FILE='input1.dat', STATUS='OLD')
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          DO 10 J=1,NSTRM
READ(10,*) RADIUS(J,1), VTHETA(J,1)
PRINT*, J, RADIUS(J,1), VTHETA(J,1)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                READ(10, *) NSTRM, NSTNS, NSTEP
PRINT*, NSTRM, NSTNS, NSTEP
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      READ(10,*) ZLOC(1)
PRINT*, ZLOC(1)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             READ(10,") VNID
PRINT", VNID
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    PRINT. . .
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                CLOSE(10)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          2
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                2
         RED THE INDUCE POR THE ANNUUS PROCENA.

1. LLIMIT, MILIMIT, RELAXY, RELAXW, THE INDUT FILE FORMAT IS:
1. LLIMIT, TOLKAT, TOLKA
                                                                                                                                                                                                                                                                                                                                                                                                      OUTPUT VARIABLES: CURV, DISSIP, BYTHAL, ENTROP, ETHETIA, EZ, HSTAG, HTOCRE, MELTA, MID, MIT, NSTNB, NSTNB, FHI, PRESS, PSTAG, PSTAG, VEIM, VELTOT, VTHETA, VMID, MHIRL, 2DELTA, ZLOC, 2VEL
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                LE PRECISION CP. CURV(51, 200). DISSIP(51, 200). DANDM(51, 200). PATALO(51, 200). ENTROP(51, 200). ENTROP(51, 200). ENTROP(51, 200). ENTROP(51, 200). ENTROP(51, 200). ENTROP(51, 200). PATOS(51, 200). TEMPRO (51, 200). TEMPRO (51, 200). TEMPRO (51, 200). TEMPRO (51, 200). PATOS (51, 200). TEMPRO (51, 200). WELM (51, 200). WELM (51, 200). WELM (51, 200). ZDEUTA (200). ZUCC(200). ZUELTA (200). ZUCC(200).
   SUBROLTINE INFUTICURY, DISSIP, DWHDM, BUTHAL, ENTROP, ETHETA, EZ, SIGNAG, HYDGES, WELLTA, NID, WAT, NSTNS, NSTNW, PHI, PRESS, 18TNA, RADIUS, ROELTA, RHO, RVEL, TEMP, TSTAG, VELM, VELTOT, THERTA, WHIRL, ZDELTA, ZLOC, ZVEL)
                                                                                                                                                                                                                                                                                                                                VARIABLES READ IN: LP, LLIMIT, MLIMIT, RELAXV, TOLM, TOLR, NSTNS, NSTRBP, ZLOC, VMID, RADIUS, VTHETA
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       INTEGER COUNT, LLIMIT, LP, MLIMIT, NSTEP, NSTNS, NSTRM, MID
                                                                                                                                                                                                                                                      STAGNATICA TEMERATURE AND PRESSURE ARE ASSUMED CONSTANT ACROSS THE INLET.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       COMMON /CONST/ CP, GANDIA, GASCON, GSUBC, MIXCO, PI
COMMON /CMTRL1/ COUNT, LLIMIT, LP, MLIMIT, NSTEP
COMMON /CMTRL2/ RELAXV, RELAXM, TOLM, TOLY, TOLR
                                                                                                                                                                                                         PROGRAM VERSION: WHIRL, VARIABLE WALL GEOMETRY
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   VARIABLEL INTERNAL TO SUBROUTINE: NONE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   DOUBLE
                                                                                                                                                         input . f
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 $\begin{array}{c} \texttt{IMMINISTED SOLUTIONS OF SOLUTIONS$ 

```
WRITE[11.*) ' '
WRITE[11.*) ' ENTROPY '
WRITE[11.*) ' ft.2/sec^2 R'

DO 70 J.NSTRM.1. 'NSTEP
CONTINUE
CONTINUE
                                                                                                                                                                                                                                                                 HRITE(11.) STACHATION PRESURE:
HRITE(11.) STACHATION PRESURE:
HRITE(11.) HFFE.

LO 80 J=NSTRM, 1. HSTRP
HRITE(11.1065) J, (PSTAG(J.1), 1=1,NSTNS)
CONTINUE.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         WRITE(11.*) ' ' WRITE(11.*) ' ' WRITE(11.*) ' ' STATIC PRESSURE' WRITE(11.*) ' JE/IE^2' DO 90 J.NSTRM. J. NSTEP CONTINUE (11.1) (1005) J. (PRESS(J.I), I=1.NSTNS)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            WRITE(11.*)
WRITE(11.*)
WRITE(11.*)
WRITE(11.*)
DO 140 J-WSTRA, J. NSTEP
WRITE(11.1007)
WRITE(11.1007)
WRITE(11.1007)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                WRITE[11.*)
WRITE[11.*)
WRITE[11.*)
WRITE[11.*)
WRITE[11.*)
Do 130 JaNSTRW 1. NSTRP
CONTINUE
CONTINUE
CONTINUE

                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         WRITE(11.*)

WRITE(11.*)

WRITE(11.*)

BY

WRITE(11.9)

MRITE(11.9)

WRITE(11.1005)

WRITE(11.1005)

WRITE(11.1005)

WRITE(11.1005)

WRITE(11.1005)

WRITE(11.1005)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            WRITE(11,*) ** STREAMLINE ANGLE*
WRITE(11,*) ** STREAMLINE ANGLE*
WRITE(11,*) ** RADIANS*
D 120 2-NSTRM, 1, -NSTEP
WRITE(11,1065) J, (PHI(J,I), I=1,NSTNS)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     100
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     110
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                                                                                                                                                                                                 20
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 96
THE POLLOWING PILES ARE ALMAYS WRITTEN ONCE THE SOLUTION HAS CONVERGED OFFUTION TO COMPANY OF THE SOLUTION HAS CONVERGED OFFUTION TO COMPANY OF THE SOLUTION TO CONTRIBE SOLUTION
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             WRITE(11.*)
                                                                                                                                                                                                                                                                                                                                                                                                                                                               WRITE[11,*) **

WRITE[11,*) **

WRITE[11,*) **

WRITE[11,*) **

DO 60 J.WSTRW.1, .NSTEP

WRITE[11,1003) J. (BYTHAL(J,I), I=1,NSTNS)

CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              WRITE(11.*)
WRITE(11.*)
WRITE(11.*)
WRITE(11.*)
WRITE(11.*)

F (**2/eec^2**)
F (**2/eec^2**)

D (**5)
WRITE(11.103)
WRITE(11.103)
WRITE(11.103)
WRITE(11.103)
WRITE(11.103)
WRITE(11.103)
WRITE(11.103)
WRITE(11.103)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 WRITE(11.*)
WRITE(11.*)
WRITE(11.*)
WRITE(11.*)
WRITE(11.*)
GASTON
WRITE(11.*)
GASTON
WRITE(11.*)
GASTON
WRITE(11.*)
GASTON
WRITE(11.*)
WR
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WRITE(21.*) DATA FROM THE INPUT SUBROUTINE.
WRITE(21.*) ALL DIMENSIONS ARE IN ft, sec. 12f, R UNLESS NOTED.
WRITE(21.*) CONSTANT STAGARION FESS AT INLET: 'PRESIN', 'pai'
WRITE(21.*) "CONSTANT STAGARION TEND AT INLET: 'TEMPIN', 'R'
WRITE(21.*) "THE 2 LOCATION OF INLET: 'ZLOC(1)*12.000, 'in'
WRITE(21.*) "THE 2 LOCATION POR LAST STATION: ','
WRITE(21.*) "THE 2 LOCATION POR LAST STATION: ','
WRITE(21.*) "2 DELFA". (inhea).
WRITE(21.*) "2 DELFA". (inhea).
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | MRTTE(21,*) | 
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      WRITE(21.*)

WRITE(21.*)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           WRITE[2].

WRITE[2].

WRITE[2].

WRITE[2].

GASCON:

GASCON:

WRITE[2].

WRITE[2].

GASCON:

WRITE[2].

GASCON:

WRITE[2].

GASCON:

WRITE[2].

GASCON:

WRITE[2].

GANGA:

GANGA:

GANGA:

WRITE[2].

WRITE[2].

WRITE[2].
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               RETURN
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  300
                  INPUT DATA POR'
ARBITRARY WHIRL DISTRIBUTION
WITH VARIABLE WALL GEOMETRY'
                                                                                                                                                                                            WRITE(11,*) ' WRITE(11,*) ' DISSIP'
WRITE(11,*) ' J DESIP'
WRITE(11,*) ' J DÉ/ft^2 sec'
DO 160 J-NSTEN, J. HSTEP
DO 160 J-NSTEN, J. HSTEP
CONTINUE
CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             WRITE[11.*)

WRITE[11.*)

WRITE[11.*)

WRITE[11.*]

DO 200 J-MSTEW

CONTINUE

CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       MRITE[11,*)

MRITE[11,*)

MRITE[11,*)

MRITE[11,*)

MRITE[11,*)

MRITE[11,*)

MRITE[11,*)

MRITE[11,1003)

MRITE[11,1003]

MRI
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 PORMAT(1X, 12, 2X, 20(P14.4, 2X))
CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         WRITE(21,*)
WRITE(21,*)
WRITE(21,*)
WRITE(21,*)
WRITE(21,*)
WRITE(21,*)
WRITE(21,*)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 160
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  200
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```
CONVERT ANNULUS GEOMETRY (HUB AND TIP) TO EE AND WRITE TO ARRAYS.
COMPUTE INSTRUCES BETWERN 4-0-8 AND STREAMLINES. ANTAL LENGTH
PRECEDING INLET 4-0-15 SEPT O ZERO AND THE LENGTH TO THE PRECEEDING
STREAMLINE RADIUS FOR THE PIRST STREAMLINE IS SET TO ZERO.
STREAMLINE RADIUS.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                THE MERIDIONAL FLOM ANGLE, PHI, LENGTH OF STREMALINE PRECEDING THE INLET, MOELTH, STREMALINE CURVATURE, CURV, AND R DIRECTION PRICITY, WELL, ARE SET TO ZERO FOR THE INLET.

PHI(J,1) = 0.0000

CURV(J,1) = 0.0000

CURV(J,1) = 0.0000

CORTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      DO 30 J=2, NSTRM
RDELTA(J, 1) = RADIUS(J, 1) - RADIUS(J-1, 1)
IF (RDELTA(J, 1) - RQ. 0.00) PRINT*, 'RDELTA ERROR IN INLET.F'
CONTINUE
                                                                                                                                                                                                                                                                                                                    ENTROP(J,1) = CP * DLOG(PRESIN) - GASCON * DLOG(PRESIN)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    2LOC(1) = 2LOC(1)/12.0D0
2DE[LA1] = 2LOC(1) = 2LOC(1-1)
2DE[LA1] : EQ. 0.00) PRINT-, "2DELTA ERROR IN INLET"
                                                                               STAGNATION ENTHALPY HAS UNITS OF fc^2/Bec^2 HSTAG(3,1) = CP + TEMPIN
                                                                                                                                                                                            STACMATION PRESSURE HAS UNITS OF 15f/ft^2 PSTAG(J,1) * PRESIN
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               DO 20 1=2,NSTNS
RADIUS(NSTRM, I) = RADIUS(NSTRM, I)/12.0D0
RADIUS(1, I) = RADIUS(1, I)/12.0D0
         FSTAG(J, 1) = TEMPIN
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                RDELTA(1,1) = 0.00D0
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         2DELTA(1) = 0.00D0
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  9
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   20
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             8
    THIS SUBROUTINE CONVERTS THE VARIABLES READ IN IMPUT TO IT AND LABLICES. TO CHEVIES THE RADIAL EQUILIBRIUM EQUATION TO GET THE AXIAL VELOCITY PROFILE THAT MUST EXIST FOR THE MILE CONDITIONS INPUT. AND COMPUTES THE VISCOUS PORCES FOR THE INLET q-o. THE RADIAL AGADIENTS FOR THE INLET q-o. THE RADIAL AGADIENTS FOR THE INLET q-o. ARE NOT COMPUTED AGAIN. MERIDIOWAL AND AXIAL GRADIENTS ARE RECOMPUTED AS NEEDED IN SUBROUTINES VISCOUS AND GRADIENTS ARE RECOMPUTED AS
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          VARIABLES INTERNAL TO THE SUBROUTINE: DVTDR, DVTDR, DVZDR, DVZDR, DVZDR2, DVZD
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  CONVERT PRESSURE FROM pai TO 156/ft.2.

PRESIN = PRESIN * 144.000
IF/PRESIN LE. 0.00) PRINT', PRESIN ERROR IN INLET'
IF/TEMPIN LE. 0.00) PRINT', TEMPIN ERROR IN INLET'
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       COMPUTE ANDIA TO ELECTRON CONTROL OF ARRAYS.

CONVERT RADIA TO ELECTRON CONTROL OF ARRAYS.
                                                                                                                                                                                                                                    INPUT VARIABLES: NSTWS, NSTWN, PRESIN, RADIUS, TEMPIN, VMID, VTHETA,
2Loc
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               DOUBLE PRECISION CP. CURV(51.200), DHODM(51.200), DISSIP(51.200)
DUTOR(51.200), DESAL(51.200), DUTOR(51.200), DUTOR(51.200), DUTOR(51.200), DUTOR(51.200), DUTOR(51.200), DUTOR(51.200), DUTOR(51.200), DUTOR(51.200), DUTOR(51.200), EXTROP(51.200), EXTROP(51.200), EXTROP(51.200), EXTROP(51.200), EXTROP(51.200), REPRETA (51.200), REPRETA (51.200), PRESIN FSTAG(51.200), RADIUS(51.200), PRESIN FSTAG(51.200), RADIUS(51.200), REPRETA (51.200), REPR
SUBROUTINE INLET(CRRV, DISSIP, DWEM, DMDO, BYTHAL, DYTROP, ETHETR, EX, NSTNG, HYDOE, NELTA, NID, MLT, NENSE, NSTRM, PRI, PRESS, PRESIM, PSTNG, RADIUS, NELTA, RHD, NYEL, TEMP, TEMP, WILLY, VELTOT, VNID, VTHETR, WHIRL, ZDELTA, ZLOC, ZVEL)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             OUTBUT VARIABLES: CURV, DISSIP, BYTHAL, ENTROP, ETHETA, EZ, HSTAG, MTOCE, WIDELTA, HID, MIT, PHI, PRESS, PSTAG, RHO, FYEL, TEMP, TSTAG, VELM, VELTOT, MHIRL, ZDELTA, ZLOC, ZVEL
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           COMMON /ZDIREC/ DHODM, DSTM
COMMON /CONSTY CP, CAMMON, GASCON, GSUBC, MIXCO, PI
ICHAGON EQ. 0.00 OR. CP. EQ. 0.00 OR. GSUBC . EQ. 0.00)
PRINTY, 'CONSTANTS ERROR IN INLET'
                                                                                                                                                                                                                                                                                                                                                      PROGRAM VERSION: WHIRL, VARIABLE WALL GEOMETRY
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           RADIUS HAS UNITS OF ft
RADIUS(J,1) = RADIUS(J,1)/12.0D0
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     INTEGER MID, NSTNS, NSTRM
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      10 J=1, NSTRM
                                                                                                                                                                                                                                                                                 inlet (
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      8
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SOME OF THE DOWNSTREAM FLOW FIELD VALUES (1. **) THOSE NOT FUNCTIONS OF AXIAL VELOCITY OR RADIUS) ARE CARRED DOWNSTREAM FROM THE INLEY q.o. AXIAL VELOCITY OR RADIUS) REST ARE CALCULATED IN SUBROUTINE EST IN.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             OF
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      CALCULATE HIDDLE STREAMLINE LOCATION TO PREPARE FOR INTEGRATION THE RADIAL EQUILIBRIUM EQUATION.

WIDE = INT (NSTRA/2) + 1

WANNEW(HID) = VMID**2
                                                                                                                                DO 50 1-2,NSTNS

DO 40 3-1,NSTNS

TSTNG (J. 1) = TSTNG (J. 1.1)

FSTNG (J. 1) = FSTNG (J. 1.1)

HSTNG (J. 1) = HSTNG (J. 1.1)

BYTNG (J. 1) = HSTNG (J. 1.1)

BYTNG (J. 1) = WTNG (J. 1.1)

WHETH (J. 1) = WHIRL (J. 1.1)

WHIRL (J. 1) = WHIRL (J. 1.1)

CONTINUE

CONTINUE
```

WHIRL(J,1) = (RADIUS(J,1) \* VTHETA(J,1))\*\*2

STACMATION TEMP HAS UNITS OF R

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160
SINE TO AMD PO ARE CURSTANT ACROSS THE INLET, ACA AND AND ARE EXECT TO INTEGRATION WITH THE LEGGL THE RADIAL EQUILIBRIUM EQUATION EXCUSS TO INTEGRATION WITH THE WHIRL TERM ON THE RIGHT HAND SIDE. INTEGRATION THE RADIAL EQUILIBRIUM EQUATION THE MAIRL TERM ON THE REST THE VAN DISTRIBUTION THAT MUST EXIST FOR THE INEIT WHIRL DISTRIBUTION.

PIRST, THE SHENE WHICH GAADIENT IS DETERMINED BY SUBROUTINE DERIV. SECOND. INTEGRATE FROM MIDDLE STREAMLINE TO TIP AND THEN TO HUB.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      THE INEET XIAL AND TA. SEPTIAL VELOCITY DISTRIBUTIONS ARE NOW KNOWN.
THE RESULTANT VELOCITY, VELTOR, IS CALCULATED TO BE USED IN FINDING
THE STATIC PLOM PIELD PROPERTIES AT THE INLET.
                                                                                                                                                                                                                                        · INTEGRATION ROUTINE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       * THE SECOND LOOP INTEGRATES FROM THE MIDLINE TO THE HUB AND GIVES

* THE SQUARED M-DIRECTION VELOCITY.

DO 100 J=MID-1, 1, -1

VALUEM (J) = VALUEM (J-1) - 4

( DMHDQ (J-1) (J-2, DOD * RADIUS (J-1)**2) *

( DMHDQ (J-1) (J-2, DOD * RADIUS (J-1)**2) *

( RADIUS (J-1) - ALDIUS (J-1,1)**2) ) *
                                                                                                                                                                                                                                                                     THE PIRST LOOP INTEGRATES PROM THE MIDLINE TO THE TIP AND GIVES THE SQUARED M-DIRECTION VELOCITY.

DO 90 J-MID-1, NSTRM
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                DO 120 3=1,NSTFM
VELTOT(J,1) = SQRT(VELM(J,1)**2 · VTHETA(J,1)**2)
                                                                                                                                                                                                                                                                                                90 J=HID-1, MSTRM
VRZNE(1) = VRZNE(4-1) -
DMLDQ(J-1)/(2.000 * RADIUS(J,1)**2) +
DMLDQ(J-1,1)/(2.000 * RADIUS(J-1,1)**2) ) *
(RADIUS(J,1) - RADIUS(J-1,1)
                                                                                                                                                              CALL DERIV(U, X. NSTNM, DUDX, D2UDX2)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    ENDIP
VELM(J,1) = SQRT(VM2NEW(J))
CONTINUE
                                                                                                                                                                                   DO 80 J=1,NSTRM
DMEDQ(J,1) = DUDX(J)
CONTINUE
                                                                                                      DO 70 J=1,NSTRN
U(J) = WHIRL(J,1)
X(J) = RADIUS(J,1)
CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           CONTINUE
                                                                                                                                                                                                                                                                                                                                                        CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         110
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             100
                                                                                                                                                                                                                                                                                                                                                        8
                                                                                                                                                                                                          80
```

STATIC TEMP HAS UNITS OF DEGREES R
TEMP[J,1] = TSTAG[J,1] - VELTOT[J,1]\*\*2/(2.050 ° CP)
IP(TEMP[J,1] : EQ. 0.00]PRINT', 'TEMP ERROR IN INLET',

STATIC PRESSURE HAS UNITS OF 156/ft-2

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CALL VISCOUS TO COMPUTE DISTRATION, ETHERN, AND EZ FOR THE INLET q-o-call VISCOUS (DISTR). ETHERN, IN WIT NSTRM, CALL VISCOUS (DISTR). ETHERN, ZZ L. WIT, NSTRM, CALL VIRENA, ZY ZY L.)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   DHODM AND DSGM ASCALLINGED FOR INFORMATION ONLY - WILL NOT CHANGE DSGM AND SIGN AS UNITS OF £/sec^2 R
DHODM HAS UNITS OF £/sec^2 R
DHODM BOTH OF STATE OF THE STATE O
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        DMHDM (J, 1) = 2.0D0 * RADIUS(J, 1)**2 * VTHETA(J, 1)/VELM(J, 1) * (ETHETA(J, 1)/RHO(J, 1))
                                                                                                                    PRINT., 'PRESS2 ERROR IN INLET', J
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           COMPUTE DATUM FOR THE ENDMALL STREAMLINES
DATUM [1,1] = 2.000 * RADIUS(1,1)*2 * VTHETA(1,1)/VELM(1,1)) *
LATIFTA(1,1)/MHO(1,1)
DATUM (NSTRA,1) = 2.000 * RADIUS (STRA,1) **2 *
LATIFTA (STRA,1)/VELM (NSTRA,1) **2 *
(ETHETA (NSTRA,1)/VELM (NSTRA,1) **2 *
(ETHETA (NSTRA,1)/RHO(NSTRA,1) **

    BENNALL STREAMLINES
    BENNALL STREAMLINES - NO HEAT TRANSFER AT ENDMALLS
    DEEM FOR THE ENDMALL STREAMLINES - NO HEAT TRANSFER AT ENDMALLS
    DEEM (NSTREAL 1) = DISSIP [1,1]/(RHO[1,1]) * TEMP[1,1] * VELM(NSTREAL) |
    LARD(NSTREAL) * TEMP[NSTREAL]

                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  COMPUTE DHODM FOR THE ENDMALL STREAMLINES

DHODM(1.1) = TEMP(1.1) + DSDM(1.1) + DMIDM(1.1) +
                                                                                                                                                                                                                                                                                                                                            DENSITY HAS UNTIS OF alwy/ft")
HOULL 1 = IRESSIG, 1 GASUBC, /(GASCON * TEMP(J,1))
F(RAD(J,1) : EQ. 0.00) PRINT*, 'RADO ERROR IN INLE", J
                                                                                                                                                                                                            HAS UNITS OF [t^2/sec^2]

ENTHAL(J,1) = HSTAG(J,1) - VELTOT(J,1)**2/2.0D0
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        DHoDM(J,1) = TEMP(J,1) * DSDM(J,1) +
(E2(J,1) * COS(PHI(J,1) )/RHO(J,1) +
DMHDM(J,1)/(2.0D0 * RADIUS(J,1)**2)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            VISCOSITY HAS UNITS OF 1bf sec/ft^2 OR slug/ft sec
HTCOEP HAS UNITS OF 1bf/sec R
MTCJ 11 = RHCJ_31 + MIXCO
HTCOEF(J,1) = MUT(J,1) + C
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    SET AXIAL VELOCITIES WITH UNITS OF \mathsf{ft/sec} \mathsf{2VEL}(J,1) = \mathsf{VELM}(J,1)
                                                                                  IP (PRESS(J, 1) . EQ. PSTAG(J, 1))
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              120 CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            CONTINUE
                                                                                                                                                                                                                       BATHAL
```

PRESS(J,1) = EXP( CP/GASCON \* DLOG(TENP(J,1)) ENTROP(J,1)/GASCON )

RETURN ENED

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| F(LP EQ 1 OR LP EQ 20) THEN | WRITE(11,1) | WRITE(11,1) | WASS FLOW IN THE ANNULUS IS:', MASTOT, 'slug/sec' | WRITE(11,1) 'STREANTUBE MASS FRACTIONS (HUB-STREAMLINE) ARE:' WRITE(11,1) 'STREAMTUBE MASS FRACTIONS (HUB-STREAMLINE) ARE:' WRITE(11,1) 'STREAMTUBE WASS FRACTIONS (HUB-STREAMLINE) ARE:' WRITE(11,1) 'STREAMLINGFOOD IS STREAMLINGFOOD IS STREAMLINGFOOD IS STREAMLINGFOOD IS STREAMLINGFOOD IN WRITE(11,1) TUBFLO(J), WFRAC(J,1)
                                                                                                                                                                                                       IF THE TOTAL MASS PRACTION FUGURE THOOLING THE ANNULUS DOES NOT EQUAL 1.0. ENGINES WILL RESULT IN THE INTERPOLATION ROUTINE. THIS SECTION RESETS WERAC AT THE TIP TO BE 1.0000.00.

IF CHERACINSTRM.1) LT. 1.0000/ THEN PRACTICATION TO THE PRINTY. TOTAL MASS FRACTION IS < 1.0, RESETTING.
    CALCULATE THE FRACTION OF MASS FLOW (MFRAC) FOR EACH STREAMTUBE FROM THE HUB TO THE STREAMLINE. THE LAST (MSTRM) STREAMTUBE SHOULD HAVE 100% OF THE FLOW IT. MFRACE IS UNIT-LESS.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           ELSE
IF (MERAC, INSTRM, 1) GT. 1.00) THEN
PRINT:
PRINT:
TOTAL MASS FRACTION IS > 1.0, SETTING TO 1.0'
MERAC (NSTRM, 1) = 1.00D0
                                                                                                                  DO 20 J=2,NSTRM
NPRAC(J,1) = TUBFLO(J)/MASTOT + NPRAC(J-1,1)
CONTINUE
                                                                              MPRAC(1,1) = 0.0000
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 RETURN
                                                                                                                                                        20
    THIS SUBROUTINE INTEGRATES THE MASS PLOM IN EACH STREAMTUBE AT THE INLET USING THE TRAPEZOIDAL RULE. NOTE THAT TUBPLO WILL, STORE NSTRWAY VALUES. EACH STREAMTURE TAKES THE NOMBER OF THE STREAMTURE ABOVE IT. STREAMTUBE I HAS SERO PLOW THROUGH IT, STREAMTUBE NSTRY HAS 100 B LOW THROUGH IT. ALSO CALCULATED IS THE MASS AVERAGED STAGNATION ENTHALPY.
                                                    VARIABLES INTERNAL TO THE SUBROUTINE: TUBFLO
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               VELOCITY IS 3-D. ZVEL AND ZVEL ARE THE SAME AT THE INLET AND PERRENDICULAR TO THE AREA, SO THE MASS FLOW RATE IS CORRECT.

MASTOT IS THE TOTAL MASS FLOW ENTERINE. MASTOT HAS TOTAL SOF a lug/sec.

TUBFLO IS THE MASS FLOW THROUGH EACH INDIVIDUAL STREAMTUBE IS THE MASS FLOW THROUGH EACH INDIVIDUAL STREAMTUBE IS THE MASS WEIGHTED STRAWATION ENTERINES.

VISCID AND ADJABATIC WALLS, HOSUM SHOULD BE THE SAME AT ALL Q-OS.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            PRINT, ' INTECRATING THE MASS FLOW AT THE INLET'
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   PRINT. CALCULATING THE STREAMTUBE MASS FLOW
SUBROUTINE PLOINT (HOSUM, HSTAG, MASTOT, MFRAC, NSTRM, RADIUS, RHO, ZVEL)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      HOSUM(1) = HOSUM(1) + TUBFLO(3) + HSTAG(3-1,1))/2.000
                                                                                                                                                                                                                                                                                                                                                                                            DOUBLE PRECISION HOSIM (200), HSTAG(51,200), NASTOT, NASTOT, NEWACK(51,200), PI, NADIUS(51,200), RMO(51,200), TUBFLO(51), 20151, 200,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 10 J=2,NSTPN
TUBFLO(J) = 0.500 * (RHO(J,1) • RHO(J-1,1)) •
F1 * (RADIUS(J,1)**2 - RADIUS(J-1,1)**2) *
(ZVEL(J,1) • ZVEL(J-1,1))/2.0D0
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           IP(RHO(J,1) - EQ. 0.00)
PRIMT*, *ERROR IN FLOINT; RHO IS 2ERO', J
IP(ZEL/J,1) - EQ. 0.00)
PRIMT*, 'ERROR IN PLOINT; 2VEL IS ZERO', J
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         IF (MASTOT . EQ. 0.00) PRINT", 'MASTOT ERROR IN FLOINT
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       COMMON /CWTRL1/ COUNT, LLIMIT, LP, MLIMIT, NSTEP
                                                                                                                                                                                                                                                                                                                                                                                                                                                                 INTEGER COUNT, LLIMIT, LP, MLIMIT, NSTEP, NSTRM
                                                                                                                                                                                                                                                              INPUT VARIABLES: HSTAG, NSTWA, RHO, RADIUS, ZVEL
                                                                                                             PROGRAM VERSION: WHIRL, VARIABLE MALL GEOMETRY
                                                                                                                                                                                                                                                                                               OUTPUT VARIABLES: HOSUM, MASTOT, MFRAC
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  MASTOT : MASTOT + TUBPLO(J)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              PI = 4.0D0 * ATAN(1.0D0)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 TUBFLO(1) = 0.00D0
MASTOT = 0.00D0
Hosum(1) = 0.00D0
                                                                         floint.f
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        8
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        0
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BE USED FOR CALCULATIONS AT THE CURRENT q-o. THIS PROBABLY SHOULD NOT BS. AN ARITHMETIC AVERAGE. BUT HOW ELSE CAN THIS BE DONE? AREA METSHTING?
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     ALTHOUGH NOT USED IN THE PROCRAM. THE WG GRADIENT IS COMPUTED AS AN AID TO HAND COMPUTATIONS TO CHECK THE PROCRAM.

BUTDR(1) = ( (MUT(1,1) - MUT(1,1)) / (RDELTA(2,1) + (MUT(2,1) - MUT(1,1)) / (RDELTA(2,1) / (RDELTA(2,1) + (MUT(2,1) - MUT(1,1)) / (RDELTA(2,1) / (RDELTA(2,1) / (RDELTA(2,1)) + (MUT(2,1) - MUT(1,1)) / (RDELTA(2,1) / (RDELTA(2,1)) )
                                                                                                                                                                                                                                                                                                                                                                                                                  CALCULATE AN AVERAGE VELOCITY FOR CURRENT q.o. USING RHOAVE, MASTOT
AND HE AREA AT THIS q.o. THE AVERAGE VEL. CITY IS USED TO GET AN
ESTHARTE OF THE RESULTANT VELOCITY FIELD.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           ASSIGN THE AVERAGE VELOCITY TO VELM: THEN CALCULATE THE FLOW FIELD
VALUES FOR EACH q-0 USING THAT VELOCITY.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     DMUTDR (NSTRM.) = ( (MUT (NSTRM.1) - MUT (NSTRM-1,1)) /
(RDELTA (NSTRM.1) / RDELTA (NSTRM.1,1) /
( (MUT (NSTRM.1) - MUT (NSTRM.2,1)) /
( (RDELTA (NSTRM.1) - MUT (NSTRM.1) / RDELTA (NSTRM.1) /
(MUT (NSTRM.1) - MUT (NSTRM.1) / RDELTA (NSTRM.1,1) )
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               TENP(J, I) = TSTAG(J, I) - (VELTOT(J, I) ••2) / (2.000 • CP)

BYTHAL(J, I) = CP * TSTAG(J, I) - (VELTOT(J, I) ••2) / (2.000

BYTHAL(J, I) = EXP (**CP(ASYON ***) DLOG (TRNP(J, I)) • (***) DLOG (TRNP(J, I)) DLOG (TRNP(J, I)) • (***) DLOG (TRNP(J, I)) DLOG (TRNP(J,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             ZVEL(J, I) = VAVE(I)
IF(ZVEL(J, I) LE. 0.00)PRINT*, ZVEL ERROK IN ESTIN
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            VELTOT(3,1) = SQRT(2VEL(3,1) **2 + VTHETA(3,1) **2)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           VAVE(I) = MASTOT/(RHOAVE * AREA(I))
IF(VAVE(I) : LE: 0:00)PRINT*, 'MASTOT ERROR IN ESTIM'
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     DMCTDR(J) = ( RDELTA, J, J, ) , RDELTA (J, 1) ) , ((MCT(J+1, 1) - MCT(J+1) ) , RDELTA (J+1, 1) , RDELTA (J+1, 1) , (RDELTA (J+1, 1) , RDELTA (J+1) ) , (RDELTA (J+1, 1) + RDELTA (J+1) ) ) , (RDELTA (J+1, 1) + RDELTA (J+1) ) )
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             AREA(1) = PI * (RADIUS(NSTRM, I) ** 2 · RADIUS(1, I) ** 2)
IF(AREA(1) = LE 0 00) PRINT*, 'AREA ERROR IN ESTIM"
                                                                                                                                                                                                                                                                                                             RHOAVE = RHOAVE/REAL (NSTRM)
IF (RHOAVE : LE: 0.6 :) PRINT*, 'RHOAVE EHROR IN ESTIM'
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    DO 120 J=1, NSTRM
VTHETA (J, I) = VTHETA (J, I-1)
                                                                                                                                                         RHOAVE = 0 00D0
DO SO JEI,NSTRM
RHOAVE = RHOAVE + RHO(J,1:1)
CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         J=2, NSTRM-1
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         130
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                130
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      120
                                                                                                                                                                                                                                                                            S
         VARIABLES INTERNAL TO THE SUBROUTINE ARE: RADRAT, VAVE, RHOAVE,
AREA, SPAN, TWEOT. TTUBE, VITAVE

DOUBLE PREDISTON AREAL2000, CP. ENTHALIS1, 2000, ENTROP[51, 200),
AMERICA MATIS1, 200, P1. PRESS[51, 200), RADIUS51, 200),
AMERICA MATIS1, 200, P1. PRESS[51, 200), RADIUS51, 200),
AMERICA MATIS1, 2001, P1. PRESS[51, 200), RADIUS51, 200),
AMERICA MATIS1, 2001, PRESS[51, 200), RADIUS51, 200),
AMERICA MATIS1, 2001, SPAN (200),
AMERICA MATIS MATICA MATIC
                                                                                                                                                              THE RIB AND TIP LOCATIONS OF STREAMLINES AT DOMNSTREAM q os THE RIB AND TIP LOCATIONS DO NOT CHANCE.

THE POLLOWING LOCATIONS ARE AT THE HUB AND TIP

RABBATILL = 0 00000

RABBATILL = 1 0000
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         CALCULATE AN AVERAGE DENSITY AT THE PREVIOUS 4-0 THIS DENSITY WILL
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        COMPUTE THE (NOW-DIMENSIONAL) RADIUS RATIOS FOR THE INLEST STREAMLINE NOW-DIMENSIONAL OF EACH STREAMLINE RADIUS FROW THE NACI
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               CALCULATE THE VALUE OF THE SPAN (TIP - HUB) AT INLET AND FOR NEXT DOMENTELM q -c.
SPAN (1) = RADIUS(NSTRM.)) RADIUS(1.1)
SPAN (1) = RADIUS(NSTRM.)) - RADIUS(1.1)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   INPUT VARIABLES, MASTOT, NSTNS, NSTRM, RADIUS, TSTAG, VELM, VTHETA
RHO
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             RDELTA(J.I) = RADIUS(J.I) - RADIUS(J.I.I)
IF(RDELTA(J.II) LE 0 00) PRINT*. 'RDELTA ERROR IN ESTIM'
CONTINUE
                                                                                                                                                                                                                                                                                                                                               THIS SUBROUTINE ESTIMATES THE FLOW VARIABLES FOR ALL THE q-os
DOMNSTREM FLOW IS ASSIMED TO BE INVISCID, ADIABATIC, AND
INCOMPRESSIBLE.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             OUTBUT VARIABLES. BYTHAL, ENTROP, HTCOEF, MUT. PRESS, RDELTA, PRUT TENP, VELTOT
         SUBROLTINE ESTINIENTIAL, ENTROP, HTOPE, 1, MASTOT, MUT, NSTW. NSTW. PRESS, BADIUS, RDEITA, RHO, RVEL, TERP. TSTAG. VELM, VELTOT, YTHETA, ZVEL.)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  CALCULATE THE RDELTA VALUES FOR THE NEXT DUANSTREAM q-0
DO 40 JT. NSTYM
RDELTA (J. I) = RADIUS(J. I) - RADIUS(J. I.)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            COMBION /CONST/ CP, GAUNA, GASCON, GSUBC, MIXCO, PI COMBION /CHTRL1/ COUNT, LLIMIT, LP, MLIMIT, NSTEP
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    INTEGER COUNT, I, LLIMIT, LP, MLIMIT, NSTEP, NSTRA
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          FIND RADIUS RATIOS
DO 20 42. NSTRA-1
RADRAT(1) = (RADIUS(1,1))/SPAN(1)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        CALCULATE RADII FOR DOMNSTREAM q o.
DO 10.3.2 NSTRN-1
RADIUS(3.1) = RADRAT(3) * SPAN(1) + RADIUS(1.1)
CONTINUE
                                                                                                                                                                                                                                                                            PROCRAM VERSION: WHIRL, VARAIABLE MALL GEOMETRY
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             CONTINUE
                                                                                                                                                                                                    est 18. f
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WRITE(12.) 'HEAT TRANSFER COEPICIENT (1bf/sec R)'
WRITE(12.) 'J HEAT TRANSFER COEPICIENT (1bf/sec R)'
DO 310 3-MSTRM.J. -NSTEP
WRITE(12.1007) J, (HTCOEF(J.K), K=1.1)
CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                               WRITE(12.*)

WRITE(12.*)

WRITE(12.*)

JUSCOSITY (lbf sec/ft^3],

DO 320 J-NSTRM.L.-NSTEP

CONTINUE

CONTINUE

WRITE(12.1007)

WRITE(12.1007)

WRITE(12.1007)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   write(12.*) dmutdr (1bf sec/ft^4)*
write(12.*) dmutdr (1bf sec/ft^4)*
do 321 j=nstrm.l.nstep
vrite(12.1011) j, dmutdr(j)
contribute(1x. 12. 2x, e20.14)
                                                                                                                                      WRITE(12.*)

WRITE(12.*)

WRITE(12.*)

DO 300 JanSTRH, J. NSTEP

MRITE(12.1007)

GOWTINE(12.1007)

WRITE(12.1007)

WRITE(12.1007)
WRITE(12,1009) J, (TEMP(J,k), K=1,I)
CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        RETURN
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           ENDIP
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           1011
                                                580
                                                                                                                                                                                                                                                                                                             300
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  320
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  330
                    MATTELLZ **)

**MATTELLZ **

**MATTEL
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            WRITE(12.*)
WRITE(12.*) STATIC ENTHALPY (ft "2/sec"2)*
DO 260 JANSTRM 1. NSTEP
WRITE(12.1007) J. (DWTMAL(J.k), K=1.1)
FORMATIK: 12. 2x, 20(E14 7, 2X))
CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          MMITE[12:*)

MMITE[12:*)

MMITE[12:*]

D 280 JASTRAL, NSTED

MMITE[12:1099]

J. (PRESSIJ, K.; K.; I.)

PORMATICIA: 12, 2x, 20(F10 4, 2x))

CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 WRITE(12.*)
WRITE(12.*)
WRITE(12.*)
WRITE(12.*)
WRITE(12.*)
WRITE(12.*)
WRITE(12.*)
WRITE(12.*)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            MATTELL2.*)

MATTELL2.*)

MATTELL2.*)

DO 250 JAMSTRM.1.-NSTEP

CONTINUE.

CONTINUE.

CONTINUE.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          MRITE(12,*)

MRITE(12,*)

MRITE(12,*)

DO 210 J.HSTERP

MRITE(12,1003)

CONTINE

CON
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               MRITE(12.*)
MRITE(12.*)
MRITE(12.*)
MRITE(12.*)
DO 240 J-MSTREP
MRITE(12.1003)
MRITE(12.1003)
MRITE(12.1003)
MRITE(13.1003)
MR
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        1005
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           750
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```
( (U(NSTRM - 1) - X(NSTRM ) ) - X(NSTRM ) ) ( (U(NSTRM - 1) - U(NSTRM ) ) ( X(NSTRM - 2) - X(SNTXM - 1) )
      775
778
778
80
81
82
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  CACULATE THE FIRST DERIVATIVE OF U FOR DIRECTION X

DUCK IAS UNITS OF U/ft

FIND DUCK AT THE WING POLYNOWIAL DIFFERENCE SCHEME

DUCK II. 1 = ( U(2) - U(1) / (X(2) - X(1)) / (X(2) - X(1)) / (X(2) - X(1)) / (X(3) - X(3) / (X(3) - X(3)) / (X(3) - X(3) / (X(3) - X(3) / (X(3) - X(3)) / (X(3) - X(3) / (X(3) - X(3) / (X(3) - X(3)) / (X(3) - X(3) / (X(3) 
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      CACCULATE THE SECOND DERIVATIVE OF U FOR DIRECTION X

DAUGHZ HAS UNITS OF U/(E. 2)

CACCULATE DAIDX2 AT THE HUB - FOLYNOMIAL DIFFERENCE SCHEME

DAUGHZ (1.1) = (2 000 / 1x(3) - x(2) ) / (x(3) - x(1) ) / (x(3) -x(1) ) / (x(3) -x(
                                             THIS SUBMOUTINE FINDS THE 1ST AND 2ND DERIVATIVES OF THE FUNCTION U WITH RESPECT TO THE X DIRECTION N IS THE SIZE OF THE ARRAYS U AND X.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       * FIND DUDK AT THE TIP USING POLYNOMIAL DIFFERENCE SCHEME

DUDK (MSTRM) : (UINSTRM) : UINSTRM) : (XINSTRM) : (XINSTRM) : (XINSTRM) : ) * (XINSTRM) : ) * (XINSTRM) : ) * (XINSTRM) : ) * (INSTRM) : ) * (INSTRM: 2) : UINSTRM) : ) * (UINSTRM: 2) : UINSTRM) : ) * (UINSTRM: 1) : UINSTRM: ) / (XINSTRM: 2) : XINSTRM: ) * (UINSTRM: 1) : UINSTRM: ) / (XINSTRM: 2) : XINSTRM: ) * (UINSTRM: 1) * (UINSTRM: 
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           · VARIABLES INTERNAL TO THE SUBROUTINE ARE U. X. N. DUDX. DZUDXZ
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   DOUBLE PRECISION DUDX (200), D2UDX2(200), U(200), X(200)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         SUBROUTINE DERIVIU. X. N. DUDX, D2UDX2,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          · OUTPUT VARIABLES DUDX, D2UDX2
                                                                                                                                                                                                                                                                                                                                                                                                         . INPUT VARIABLES U, X, N
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          INTEGER N
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CALCULATE DUDX2 AT THE TIP - POLYNOMIAL DIFFERBNCE SCHEME DYZDRZ INSTRULI 1 - (2 DD C. YKINSTRUL) - (XINSTRUL) 1 - XINSTRULI) 1 - KINSTRULI) / (XINSTRULI) - (XINSTRULI) -

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THE MERIDIONAL FLOW ANGLE (PH1) HAS UNITS OF RADIANS.

PH1 FOR THE LAST COMPATING STATION

IF (1 : EQ. NSTNS) THEN

DO 50 Js.1 NSTNS)

PH1 (J.NSTNS) = ATMX ((RADIUS(J,NSTNS) - RADIUS(J,NSTNS-1)).
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         FIND THE Z AND COMPONENTS OF THE VELOCITY. ZVEL AND RYEL HAVE
UNITS OF £1/20C
THIS IS THE 15T THE LAFT LINDON. ZVEL IS KNOWN FROM ESTIM AND INLET.
VELM AND RYEL ARE UNKNOWN.
IF NOT THE FIRST LTEMT. JM. VELM IS KNOWN FROM VELO. ZVEL AND RVEL
ARE UNDATED USING LATEST VERW VALUES.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  DATA FROM SUBROUTINE CURVE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       NOT AT DND OF FLOW FIELD, NSTNS > 2, SO FOR MIDDLE

q-o REGION CALCULATE THE DERIVATIVES USING SUBROUTINE DERIV.

DO 10 - 12.1, NSTRN

U(1) = RADIUS(J, I)

X(J) = 2LOC(J, I)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                DO 90 3-1, NSTRM
IF(COUNT TO 20 1)THEN
VELM(3,1) = ZVEL(3,1)/COS(PH1(3,1))
RVEL(4,1) = ZVEL(4,1) * TAN (PH1(3,1))
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         WRITE(13.*) 'gal.dir VERSION I = ', I WRITE(13.*) 'gal.dir VERSION I = ', I
                                                                                                                                                                                                                                                                                                            CURV(J, I) = D2RDZ2(J, I)/
((I.0D0 + DRDZ(J, I)**2)**1.5D0
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   ZVEL(J, I) = VELM(J, I) • COS(PHI(J, I))
RVEL(J, I) = VELM(J, I) • SIN(PHI(J, I))
CONTINUE
                                                                                                                                                                                                          CALL DERIV(U, X, NSTRM, DUDX, D2UDX2)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   ELSE
PHI FOR THE MIDDLE BLOCK OF THE PLOW FIELD
DO 60 J-1, NSTR
PHI (J, 1) = 0,550 *
PHI (J, 1) = 0,550 *
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       I BO NSTNS OR.
ID I EQ NSTNS) THEN
                                                                                                                                                                                                                                          DO 40 J=1,NSTRM
DZVDR(J,I) = DUDX(J)
DZRDZ(J,I) = DZUDX2(J)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       IF(LP EQ. 3 AND I
LP EQ. 20 AND
CONTINUE
ENDIP
ELSE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              CONTINUE ENDIF
                                                                                                                                                                                                                                                                                                                                          CONTINUE ENDIP
                                                                                                                                                                         CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      CONTINUE
                                                                                                                                                                                                                                                                                                                                 .
                                                                                                                                                                           30
                                                                                                                                                                                                                                                                                                                                                9
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                     2
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             9
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        90
                     - CURV HAS UNITS OF 1/ft.
- PHI MAS UNITS OF RADIANS
- RVEL AND EVEL HAVE UNITS OF 1/6 - CONTINUED CONTINU
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                COMPATE THE STREAMLINE CURVATURE NOTE THAT THESE ARE 2 DIRECTION
DERIVATIVES.
                                                                   THIS SUBBOUTINE CALCULATES THE CURVATURE, CURV, THE FLOW ANGLE OF THE FLOW PIELD, PHI. THE 2 AND R DIRECTION VELOCITIES, ZVEL AND RVEL.
               SUBROTTINE CURVE, CURV. I. NSTNS, NSTRM, PHI, RADIUS, RVEL, VELM, & 2DELTA, 2VEL)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 SIMPLE BACKMARD DIPPERENCE FOR LAST q.o WITH NSTNS = 2
DO 10 J=1.NSTNM
DRIDE(J,NSTNS) = (RADIUS(J,NSTNS) - RADIUS(J,NSTNS-1))/
& ZDELTA,NSTNS)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             COMPUTE CHRVATURE FOR LAST q-o CURV HAS UNITS OF 1/ft CURV IJ.NSTNB) 1 = DRDZ2 (1 JRSTNB)/ (1 (1 000 + DRDZ1CJ.NSTNB)**2)**1 5D0)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            USE POLYMONIAL DIPFERBNCE FOR LAST 4.0 NITH NSTNS > 2
DO 20 J-1, NSTNN
DOZ.J., NSTNS) = (RADIUS(J.NSTNS) - RADIUS(J.NSTNS-1))
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                (2DELTA (NSTNS) / 2DELTA (NSTNS-1)) ((RADIUS (J. NSTNS) - RADIUS (J. NSTNS-2)) / (I.DELTA (NSTNS) - RADIUS (J. NSTNS-1)) / (RADIUS (J. NSTNS) - RADIUS (J. NSTNS-1)) / 2DELTA (NSTNS-1)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               ASSUME LINEAR 2ND DERIVATIVE IF ONLY 2 q-oS EXIST D2RD22(J,NSTNS) = 0.00D0
                                                                                                                                                                                                                                                                                                                                                                                                                                                               INTEGER COUNT, I. LLIMIT. LP. MLIMIT, NSTEP, NSTNS, NSTRM
                                                                                                                                                                                                                                                                           DRDZ AND D2RDZ2
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  COMBICN /CONST/ CP. GANDIA, GASCON, GSUBC, MIXCO, PI COMBICN /CHTRL1/ COUNT, LLIMIT, LP, MLIMIT, NSTEP
                                                                                                                     PROGRAM VERSION: WHIRL, VARIABLE MALL GEOMETRY
                                                                                                                                                                                                        INPUT VARIABLES I. NSTNS, NSTRM, RADIUS, VELM
                                                                                                                                                                                                                                                                         VARIABLES INTERNAL TO THE SUBROUTINE ARE:
                                                                                                                                                                                                                                        OUTPUT VARIABLES: CURV, PHI, RVEL, 2VEL
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       D2RD22 (3, NSTNS)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       IP (NSTNS EQ. 2) THEN
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   POR LAST q -0
IF (I EQ MSTNS) THEN
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               CONTINUE
                                                                                      Curve f
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               2
```

```
STRAIN IS A COLLECTION OF VARBLES WIFE OCUR TOGETHER. THE NAME
COMES FROM THE SOURCE OF THE TERMS - HIE STRAIN RATE.
TRIAIN MAS UNITS OF I/S sec.

DSTRAIN IS UNITS OF I/S sec.

DSTRAIN IS THE RADIAL DERIVATIVE OF STRAIN. IT HAS UNITS OF 1/8*C.

DSTRAIN IS THE RADIAL DERIVATIVE OF STRAIN. IT HAS UNITS OF 1/8*C.

DO 90 JJ. NOTOR

STRAIN JJ. = RADIUS(J. I) *

LUTTOR (J. I) - VTHETA (J. I) / RADIUS(J. I) )
                                                                                                                                                                                                                                                                                                                                                                    CACCULATE THE 2-DIRECTION VISCOUS BODY PORCE FOR THE FIELD.

EZ HAS UNITS OF VISCOUS PORCE FRO UNITY VOLUME OP 18/7(£^3)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                CALCULATE THE THETA BIRECTION VISCOUS BODY FORCE FOR THE FIELD.

ETHETA HAS WITS OF 1bf/fc^3.
                                                                                                                                                                      CALLIMORE USES ZERO DISSIPATION FOR INVISCID ENDMALL BOUNDARY CONDITION. I THINK THAT WIT WHOULD BE ZERO AT THE ENDMALLS AS THE BOUNDARY CONDITION AND THAT HYCOFF SHOULD BE ZERO AT THE ENDMALLS POR THE ADIABATIC BOUNDARY CONDITION.
DISSIPATION IS ZERO FOR INVISCID ENDMALL BOUNDARY CONDITION
DISSIPATION 15 ZERO FOR INVISCID ENDMALL BOUNDARY CONDITION
                                                                DO 50 J= 1,NSTRN
DISSIP(J,I) = MTF(J,I) • ( DYZDR(J,I)••2 •

[DYTDR(J,I) - VTHETN(J,I)/RADIUS(J,I))••2 )
                                                                                                                                                                                                                                                                                                  DISSIPATION IS ZERO FOR INVISCID ENDMALL BOUNDARY CONDITION DISSIP(NSTRM, I) = 0.00D0
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                EZ IS ZERO FOR INVISCID ENDMALL BOUNDARY CONDITION EZ (1, 1) = 0.00D0
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   EZ IS ZERO FOR INVISCID ENDMALL BOUNDARY CONDITION EZ INSTRM.1) = 0.0000
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            DO 100 J=1,NSTRM
ETHETA(J,1) = (1.0D0/RADIUS(J,1)) * DUDX(J)
CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                         DO 60 J=1,NSTRM
U(J) = RADIUS(J,I) * NU(J,I) * DVZDR(J,I)
X(J) = RADIUS(J,I)
CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              DO 70 J=1,NSTRM
E2(J,I) = (1.0D0/RADIUS(J,I)) • DUDX(J)
COMTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               CALL DERIV(U. X. NSTRM, DUDX, D2UDX2)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       DO 90 J=1,NSTRM
U(J) = NU(J,1) • STRAIN(J,1)
X(J) = RADIUS(J,1)
CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           CALL DERIV(U, X, DUDX, D2UDX2)
  DVTDR (J, I) = DUDX (J)
CONTINUE
                                                                                                        CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  100
                   0
                                                                                                                         2
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              9
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 10
  CACULANT THE RADIAL GRADIENTS OF Z-VELOCITY. THETA VELOCITY, AND THE DISSIPATION FOR THE FLOW FIELD.

DYZER (ANIAL VELOCITY GRADIENT) HAS UNITS OF 1/sec
DYTAR (THERA VELOCITY GRADIENT) HAS UNITS OF 1/sec
DISSIP HAS UNITS OF POWER PER UNIT VOLUME OR 16 f/sec
PIND DYLOR, DATER AND DISSIPATION AT THE HUB
DO 20 341, METRIN
                                                                                                                                                                                                                                                                                                                               - DISSIP HAS UNITS OF 156/ft.3.
- ETHERN HAS UNITS OF 156/ft.3.
- EZ HAS UNITS OF 156/ft.3.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 COMPATE ARIEN BASED ON LATEST STREAMLINE LOCATIONS FROM
ESTIM OR RADIAL.
                                                  INPUT VARIABLES: I, MUT, MSTNS, NSTRM, RADIUS, RDELTA, VELM, VTHETA 2VEL
                                                                                                                                       THIS SUBBOUTINE CALCULATES THE VISCOUS BODY FORCES (ETHETA AND EZ) AND DISSIPATION
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          DO 10 J=2.MSTEM

REGETA(J, I) = RADIUS(J, I) - RADIUS(J-1, I)

10 CONTINUE

ROBELTA (J, I) - LE. 0.000) PRINT*, 'RDELTA ERROR IN VISCOUS'
                                                                                                                                                                                                                                                                                DVZDR, DVZDR2, IWTDR,
DVTDR2, DMCTDR
SUBROUTINE VISCOUS(DISSIP, ETHETA, EZ, I, MUT, NSTNS, NSTRA, & RADIUS, RDELTA, VELM, VTHETA, 2VEL)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             INTEGER CYMMT, I. LLIMIT, LP. MLIMIT, NSTEP, NSTRM, NSTW
                                                                                                                                                                                                                                                                                                                                                                                                                   DOUBLE PRECISION CP. DISSIP(51, 200). DSTROR(51, 200).
UTTR(51, 200). DSTROR(51, 200). DATROR(51, 200).
DMEDM(51, 200). ETHETA(51, 200). EX (51, 200).
GARBAL, GASCON, GABLE, HINCO, MET(51, 200).
RADIUS(51, 200). RDELTA(51, 200). STRAIN(51, 200).
VEHETA(51, 200). VEHM(51, 200). ZVEL(51, 200).
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            COMBION /CONST/ CP, GANDA, GASCON, GSUBC, MIXCO, PI COMBION /CHTRL1/ COUNT, LLIMIT, LP, MLIMIT, NSTEP
                                                                                                     PROGRAM VERSION: WHIRL, VARIABLE MALL GEOMETRY
                                                                                                                                                                                                                                                                                VARIABLES INTERNAL TO THE SUBROUTINE ARE:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                CALL DERIV(U, X, NSTRM, DUDX, D2UDX2)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       CALL DERIY(U, X, NSTRM. DUDX, D2UDX2)
                                                                                                                                                                                                                                             OUTPUT VARIABLES: DISSIP, ETHETA, EZ
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      DO 30 J=1,NSTRH
DVZDR(J, I) = DUDX(J)
DVZDR2(J, I) = D2UDX2(J)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              U(J) = ZVEL(J, I)
X(J) = RADIUS(J, I)
CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           U(J) = VTHETA(J,I)
X(J) = RADIUS(J,I)
CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               DO 40 Jal, NSTRM
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    2
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            2
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BNDIF
300 CONTINUE
RETURN
BND BND
                                  WRITE(14.*) ' WRITE(14.*) ' WRITE(14.*) ' WRITE(14.*) ' ETHETA' DO 140 Janstra, ', -NSTEP WRITE(14.1014) J. (ETHETA (J.k), K=1,NSTNS) CONTINUE
 DO 235 J=NSTRM, 1, -NSTEP WRITE(14, 1014) J, (atrain(J,k), K=1,NSTNS) CONTINUE
                 235
 DATA FROM SUBROUTTINE USCOUS

- DATA FROM SUBROUTTINE USCOUS

- PILE 1014-3 det 18 A CHECK ON THE CALCULATION PROCEDURE AT THE INLET

- IF (COMPT. EQ. 0.100 TO 300

- IF (COMPT. EQ. 0.100 TO 300

- IF (LP. EQ. 10 AND. 1 EQ. NSTNS) THEN
                                                                                                       WRITE(14.) '91.dir VERSION I = '. I
WRITE(14.) '91.dir VERSION I = '. I
WRITE(14.) 'WRITE(14.) '
WRITE(14.) 'IMTR PROM VISCOUS PORCE SUBROUTINE: output 4.dat'
WRITE(14.) 'ITERATION CCUPT IS: '. COUPT
WRITE(14.) '
* ETHETA 15 ZENO FOR INVISCID ENDMALL BOUNDARY CONDITION C ETHETA (1.1) = 0.00D0
                      WRITE(14.)
WRITE(14.)
WRITE(14.)
DO 180 JANSTRM, 1, -NSTEP
WRITE(14.1014) J. (DVZDR2(J.K), K=1,NSTNS)
                                                                                                                                                                                                                                                                                                                                                                                                      WRITE(14.)
WRITE(14.)
DO 20 J-WSTRM, 1, WSTEP
WRITE(14.1014) J. (DISSIP(J.K), K=1, NSTNS)
CONTINUE
                                                                                                                                                                                                                                                                                                                                          WRITE(14.*)

WRITE(14.*)

WRITE(14.*)

DO 200 JANGTRM 1, -NSTEP

WRITE(14.1014) J. (DVTDR(J.k), K=1.NSTNS)

CONTINUE
                                                                                                                                                                                                                    MRITE(14.*) **
MRITE(14.*) **
MRITE(14.*) **
DO 170 J=MSTRM 1. HSTEP
WRITE(14.1014)3. (DVZDR (J.K), K=1, NSTNS)
CONTINUE
                                                                                                                                                                WRITE(14.*)

WRITE(14.*)

WRITE(14.*)

DO 210 J-NSTRM 1, NSTEP

WRITE(14.1014) J, (EZ(J.K), K=1.NSTNS

CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             WRITE(14,*) ...
WRITE(14,*) ...
WRITE(14,*) .J
                                                                                                                                                                                                 101
                                                                                                                                                                                                                                                            170
                                                                                                                                                                                                                                                                                                                       180
                                                                                                                                                                                                                                                                                                                                                                                 200
                                                                                                                                                                                                                                                                                                                                                                                                                                            220
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      230
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DHOIN, DHENN, AND DSIGN ARE CALCULATED IN ORDER TO UPDATE THE FLOW FIELD VARIABLES. DHENN IS THE WHITL GRADIENT.

DEGN HAS WAITS OF FK feec? R
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        * DANIDM HAS UNITS OF ft^3/sec^2
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        • DMoDM HAS UNITS OF ft/sec^2
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         DO 60 J=1,NSTRM
DMHDM (J, 1) = 2.0D0 * RADIUS(J, I) **2 * VTHETA(J, I) /VELM (J, I)
(ETHETA (J, I) /RHO (J, I))
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      THIS EQUATION FOR DSDM DOES NOT ACCOUNT FOR HEAT TRANSFER DSDM(1,1) = DISSIP(1,1)/(RHO(1,1) * TEMP(1,1) * VELM(1,1))
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     DO 50 J=1,NSTRM
THIS EQUATION FOR BSDM ACCOUNTS FOR HEAT TRANSFER
DSDM(J,1) = (1.000/(RADIUS(J,1)) * RHO(J,1) * TEMP(J,1) *
DISSIP(J,1)) * DJDK(J) *
DISSIP(J,1)/(RHO(J,1) * TEMP(J,1) * VELM(J,1))
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       THIS EQUATION FOR DSIM DOES NOT ACCOUNT FOR HEAT TRANSFER DETM (NETMIL) I - DISSIP INSTRM, I) * VELMINSTRM, I) * VELMINSTRM, I) * OF THE NETMIL I - VELMINSTRM, I 
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               DO 40 3=1, NSTRM
U(J) = (RADIUS(J, I) * HTCOEP (J, I) * DTDQ(J, I)
X(J) = RADIUS(J, I)
CONTINUE
                                                                                                                                                                                                                                                                                                                                 ENDMALL BOUNDARY CONDITION - NO HEAT TRANSER DTDQ(1, 1) = 0.000
                                                                                                                                                                                                                                                                                                                                                                                                              ENDMALL BOUNDARY CONDITION - NO HEAT TRANSER DITDQ(NSTRM, I) = 0.000
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    CALL DERIV(U, X, DUDK, D2UDX2)
                                                                                                                                        CALL DERIV(U, X, DUDX, D2UDX)
                                                                                                                                                                                         DO 30 J=1,NSTRM
DTDQ(J,I) = DUDX(J)
CONTIN')E
20 J=1,NSTRM
U(J) = TEMP(J, I)
X(J) = RADIUS(J, I)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          DO 70 J=1,NSTRM
DHoDM(J, I) = T
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             CONTINUE
                                                                                   CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             CONTINUE
   8
                                                                                   20
                                                                                                                                                                                                                                                    9
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   2
DIACID, DEDD, DWIDH, BYTHAL, ENTROP, HSTAG, HTODEP, MOELTA, MUT, PRESS, PETAG, RHO, TEMP, TSTAG, VELTOT, VTRETA, WHIRE,
                                                                                                                                                             CALCULATE THE LENGTH OF THE STREAMLINE (MENIDIONAL DIRECTION) BETWEEN
COMPUTING STATIONS. NDELTA HAS UNITS OF It.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     . VARIABLE UNITS ARE LISTED WITHIN THE SUBROUTINE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  CALCULATE THE RADIAL GRADIENT OF TEMPERATURE
DITO HAS UNITS OF R/ft.
                                                                                                                                                                                                                                                                                                                              SINCE THERE ARE NO BLADES IN THE AMENIUS, VISCOUS EPPECTS
ARE THE GOLY NAY THEN SPROAMENION BETHALDY CHANGES CAN GOOD.
NOTH THAT BADING GAADIENT CALCULATIONS OPERATE ALONG EACH QUASI-
OFTHOGOME, MILE THE MERIDIGAL GRADIENT CALCULATIONS OPERATE ALONG
EACH SPREAM INIE.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          DISSIP, ENTNAL, ENTROP, ETHETA, EZ, KSTAG, HTCOEP, I, MAT, NSTNS, NSTNS, PII, PRESS, PSTNG, RADIUS, RECKLTA, RRD, TEMP, TSTNG, VELTOT, VELM, VTHETA, MAIRL, ZDELTA
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  LE PRECISION CP. DHODMISI, 2001, DMODQ(51,200), DTDQ(51,200), DISSIP (51,200), DSMUSI(51,200), DMODQ(51,200), DMODQ(51,200), DMODQ(51,200), DMODQ(51,200), DMODQ(51,200), DMODQ(51,200), DMODQ(51,200), ETHETAS(51,200), ETHETAS(51,200), ETHETAS(51,200), ETHETAS(51,200), ETHETAS(51,200), MODGLTA (51,200), MIXCO, MOTG(51,200), MODGLTA (51,200), MIXCO, MOTG(51,200), PSTAG(51,200), PSTAG(51,200), PSTAG(51,200), TSTAG(51,200), TSTAG(51,200), TSTAG(51,200), TSTAG(51,200), TSTAG(51,200), WIRL(51,200), WIRL(51,200), WIRL(51,200), WIRL(51,200), WIRL(51,200), WIRL(51,200), WIRL(51,200), WIRL(51,200), WIRL(51,200), EDUTA (200)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        VARIABLES INTERNAL TO THE SUBROUTINE ARE: DIDO, D72DQ2, DSDM, DKDQ. DANDM, DHODM
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       INTEGER COUNT, I, LLIMIT, LP. MLIMIT, NSTEP, NSTNS, NSTRM, trip
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         10 J=1, NSTTW

MDELTA(J, I) = SQRT( (RADIUS(J, I) - RADIUS(J, I-1))**2 +

ZDELTA(I)**2 )

IP(MDELTA(J, I) : EQ. 0.00)PRIMT*, 'MDELTA ERROR IN GRADIENT'
                                                                                                                                                                                                                                                 PROCRAM VERSION: WHIRL, VARIABLE WALL GEOMETRY, AND GALLIMORE'S METHOD OF q-0 ITERATION.
SUBROUTINE CALADIDATICHACO, DISSIP. DOSD. DWIDH, DAHLDH, DARRON, BATHAL, BATROP ETHERN. EZ. HSTRG. HTCOEF. I. MORLTH, MAT. NETNE. MSTRM, PHI. PRESS. PSTRG. MADIUS. ROELTH, MO. TENP. TSTRG. VELTOT. VELM. VTHETA. MAIRL. ZEBLTH).
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            COMMON /CONST/ CP. GAMMA, GASCON, GSUBC, MIXCO, PI
COMMON /CPITALI, COUNT, LLIMIT, LP, MLIMIT, NSYEP
COMMON /CPITAL? RELAXW, RELAXW, TOLM, TOLW, TOLR
COMMON /ZDIREC/ PROCNE, DSUM
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     oldwh(j) = whirl(j,i)
                                                                                                                                                                                         gel.dir/gredient.f
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   OUTPUT VARIABLES:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          INPUT VARIABLES:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            DOUBLE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             8
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             2
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CALCULATE THE NEW VALUE OF STACKATION BATKALPY USING THE MENDIOWAL
GRADIENT DETERMINED ABOVE. FROW THE STACKATION BETRALPY. THE STATIC
BATKALPY AND TERMERATURE MAY BE POUND. USING THE EXTROPY GRADIENT
DETERMINED ABOVE, THE ENTROPY MAY BE UPDATED. COMBIN'NG THE ENTROPY

```
| DEBLOOK DATA FROM SUBSOUTINE CALCES INTO A FILE SO I SERVICE CALCES CAND. I EQ. NSTNS) THEN CALCES CAND. I EQ. NSTNS) THEN CALCES CAND. I EQ. NSTNS) THEN CALCES CAND. I E. I SERVICE CALCES CALCES CAND. I E. I SERVICE CALCES CAND. I E. I SERVICE CALCES CAND. I SERVICE 
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       ONCE THE NEW HETWAC AND BATROOK HAVE BEEF CALCULATED. THE RADIAL GRADIENTS OF STRANTION BYTHALPY, ENTRODY, AND WHIRL CAN BE POUND.

DO 150 J=1, NFTRM U. J. STRANTION OF STRANTIUS (3, 1) STRANTION OF S
                                                                                                                                                    RHO(J,1) = (PRESS(J,1) * GSUBC)/(GASCON * TEMP(J,1))
IP(RHO(J,1) .LE. 0.00D0/THEN
PRINT*, *RHO UPDATE ERROR IN GRADIENT*
RHO(J,1) = RHO(J,1)
                                                                       /ELTOT(J, I) = SQRT(VELM(J, I) **2 + VTHETA(J, I) **2)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 CALL DERIV(U, X, NSTRM, DUDX, D2UDX2)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         CALL DERIV(U, X, NSTRM, DUDX, D2UDX2)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 \mathsf{MUT}(J, I) = \mathsf{RHO}(J, I) + \mathsf{MIXCO}

\mathsf{HTCOEP}(J, I) = \mathsf{MOT}(J, I) + \mathsf{CP}
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               WRITE(15,*) ** DVMDM**
WRITE(15,*) ** J DVMDM**
DO 260 J=NSTRM,1,-NSTEP
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                DO 180 J=1, NSTRM
DMHDQ(J,I) = DUDX(J)
180 CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            DO 160 J=1, NSTRM
DHODQ (J, I) = DUDX (J)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   DO 170 J=1,NSTRM
DSDQ(J,I) = DUDX(J)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       U(J) = ENTROP(J,I)
X(J) = RADIUS(J,I)
CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              U(J) = WHIRL(J,I)
X(J) = RADIUS(J,I)
170 CONTINUE
                                                                                                                                                                                                                                                                                                                                                                         ENDIP
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     130
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              160
                   TEMP(J, I) = ENTMAL(J, I)/CP
IP(TEMP(J, I) .LE. 0.00D0)PRINT*, 'TEMP UPDATE ERROR IN GRADIENT'
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  ERBORS RESULT IF e IS RAISED TO A LARGE NEGATIVE NUMBER
PRESS(J.I) = TEMP(J.I)**(CP/GASCON) * EXP(-ENTROP(J.I)/GASCON)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      HSTAG AT GOOT I. STREAMINE, J. IS: ', HSTAG AT GOOT I. STREAMINE', J. IS: ', HSTAGJJJJ, 2000 PRINT', STAG BYTHAL BEING SET TO VALUE OF ', HSTAGJJJJ PRINT', 'TSTAG IS', HSTAGJJJJCP PRINT', 'TSTAG IS', HSTAGJJJJCP
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              ENTROP(J, I) = ENTROP(J, I)/2.0D0
PRINT: NEC ENTROP BEING SET TO VALUE OF , ENTROP(J, I)
PRINT: NEC ENTROP BEING SET TO VALUE OF , ENTROP(J, I)
PRINT:
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            ENTROPY UPDATED

STROP(J.1) = ENTROP(J.1-1) + MDELTA(J.1) * DSCH(J.1)

If (ENTROP(J.1) = LE 0.00)THEN

FRINT* : SPIROPY AT q-0*, I. STREAMINE*, J. * IS: *,

& BUTROP(J.1) = DOTTOP AT GROWN AT 

    VARIABLE WHIRL AND VTHETA UPDATED
    MATRLO 11 - MITRLO 11-1 ODMEDNIO 11 ODMEDNIO 11 ODMEDNIO 11 ODMENIO 11 ODMENIO 11 ODDME (0.) 11 ODD
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         IF (WHIRL(J.I) .LT. 0.00)THEN
PRINT., 'WHIRL AT q-o', I, STREANLINE', J, 'IS: ',
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     * STACHATION ENTHALPY UPDATED
HSTNG(J, I) = HSTNG(J, I.) + WDELTA(J, I.) * DHODM(J, I.)
IFHTSTNG(J, I.) LE 0.00 THEN
PRINT: HSTNG AT q-0', I, STREMINE, J, 'IS:',
AND TEMPERATURE, THE NEW PRESSURE AND DENSITY MAY BE POUND.
MINICLYA HAS UNITS OF PERTOR AND DETAIL MAY BE POUND.
TSTAG AND DETAIL MAYE UNITS OF BLU/lbm
TSTAG AND TEMPE WHITS OF BLU/lbm
TSTAG AND TEMPE WHITS OF BLU/lbm
RETNOP HAS UNITS OF BLU/lbm
PRESS AND PSTAG HANE UNITS OF DE/ft-2
DENSITY HAS UNITS OF DE/ft-2
MAT HAS UNITS OF DE/ft-2
MAT HAS UNITS OF DE/ft-2
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          PSTAG(J, I) = PRESS(J, I) * (TSTAG(J, I)/TEMP(J, I))**
(GAMMA/(GAMMA - 1.0D0))
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           THE REST OF THE PLOW FIELD VARIABLES ARE NOW UPDATED TSTAG(J, I) = HSTAG(J, I)/CP
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   · COMPUTE NEW VTHETA VTHETA (J.I) / RADIUS (J.I)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                whire AT q-o', I, 'S'
whire (J, I) = whire (J, I)/2.0D0
print. (J, I) = whire (J, I)/2.0D0
print.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 DO 130 J=1, NSTRW
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        PRINT. E
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         KOTE
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NEW ENTHALPY
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        NEW ENTROPY
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      WRITE(15.*)

WRITE(15.*)

DO 310 J-MSTRM 1, -NSTEP

CONTINUE

CONTINUE

CONTINUE

WRITE(15.1017) J. (DHODM(J.K), K-1.NSTNS)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               WRITE(15.*)
WRITE(15.*)
DO 350 J-WSTRM.1. WRITE
WRITE(15.1019) J. (DH-DOQ(J,K), K=1.NSTNS)
CONTINUE
WRITE(15, 1015) J. (DVIEDK(J,K), K=1,NSTNS)
CONTINUE
                                                                                                                        MRITE(15.*) **
MRITE(15.*) **
MRITE(15.*) **
TEMP*
DO 270 J-MRITE(15.1015) **
CONTINUE
CONTIN
                                                                                                                                                                                                                                                                                                                                                                                     MRITE(15.*) **
MRITE(15.*) **
MRITE(15.*) **
DO 260 JAMETREL 1-METED

MRITE(15.1015) **
MRITE(15.1015)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  WRITE(15.*)
WRITE(15.*)
WRITE(15.*)
DO 320 JAMETER, J. MSTEP
DO 320 JAMETER(15.1017) J. (DEDQ(J.K), K=1,NSTNS)
CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       1019
                                  9
                                                                                                                                                                                                                                                                                               230
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                280
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 320
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              330
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       350
```

RETURN EXP MRITE [15.\*)

MRITE [15.\*)

D 430 J-HSTRM J, -NSTEP

CONTINUE

CONTINUE

WRITE [15.1021) J, (VITHETA (J.K.), K=1, NSTNS) WRITE[15.\*)

WRITE[15.\*)

WRITE[15.\*)

DO 420 JANSTRW, 1. -NSTEP

CONTINUE

CONTINUE

WRITE[15.1021)

J. (DMHDQ(J,K), K=1,NSTNS) WRITE(15.\*) 'J DAKDN'
DO 400 J-ENSTRAM, J-NSTRAM
WRITE(15.1021) J. (DMKIDN(J.K), K=1,NSTNS)
PONDAT(1X, 12, 2X, 20(P16.4, 2X)) ENDIF 1021 410 420 **\$**30 

NEW WHIRL'

WRITE(15,\*) . .

.

```
PRINT, INTEGRATING THE NOMENTUM EQUATION
PRINT, ITER, ITERATION STATION NUMBER: ', I
INTERRATE THE NOOD THE STATION POR THE CURRENT G-O
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             RELAX THE RERIDIONAL VELOCITY CHANGE. USING LATEST LOCAL ITERATION VELW VALUES TO UPDATE OLUNA? FOR NEXT LOCAL ITERATION
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   DHBAR(J) = DHODQ(J-1,1) + DHODQ(J,1)
TBAR(J) = TEMP(J-1,1) + DSDQ(J-1,1) + TEMP(J,1) + DSDQ(J,1)
WBAR(J) = DWEDQ(J-1,1)/(2.0D0 + RADIUS(J-1,1)**2) +
DWEDQ(J,1)/(2.0D0 + RADIUS(J,1)**2)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             DHBAR(J) = DH-DQ(J+1,1) + DH-DQ(J+1,1) TBAR(J) = TEMP(J+1,1) + DSQ(J+1,1) + DSQ(J+1,1) + DSQ(J+1,1) + DSQ(J+1,1) + DSQ(J+1,1) + DSQ(J+1,1) / (2.000 + RADIUS(J+1,1) + 2) + DSQ(J+1,1) / (2.000 + RADIUS(J+1,1) + 2)
   THE FIRST LOOP INTEGRATES PROM THE NIDLINE TO THE TIP AND GIVES THE SQUARED VELOCITY.

TO 20 3 HID-1, NSTRM
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         IF (ABS.(AFUN.(J.)) . LE. 1, 0E-8/THEN
VM2NEW(J.) = VM2NEW(J-1) + BFUN.(J.) + RADIUS.(J-1,1))
(RADIUS.(J.) - RADIUS.(J-1,1))
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            IF (ABS.(AFUN.(J.) LE 1 0E-10)THEN VW2NEW(J.) : VW2NEW(J.) : VW2NEW(J.) : RADIUS.(J.) : RADIUS.(J.1) )
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             THE SECOND LOOP INVEGRATES FROM THE MIDLINE TO THE HUB AND GIVES THE SQUARED VELOCITY.

DO 30 3 MID-1, 1, -1
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        XI = EXP(-AFUN(J) * (RADIUS(J, I) - RADIUS(J-1, I)))
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              X1 = EXP(-AFUN(J) * (RADIUS(J, I) - RADIUS(J+1, I)))
                                                                                                                                                                                                                                                                                                                                                                                         APUN(J) = -( COS(PHI(J-1, I) ) + CURV(J-1, I) +
COS(PHI(J-1)) + CURV(c, I) +
SIN(PHI(J-1)) + DVMDN(J-1, I)/VELN(J-1, I) +
SIN(PHI(J-1)) + DVMDN(J-1)/VELN(J-1, I) +
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                ELSE
VAZNEM(3) = VAZNEM(3-1) * X1 *
(BFUN (3)/AFUN (3)) * (1.0D0 - X1)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        ELSE VMZNEM(J) : VMZNEM(J+1) • X1 • (1.0D0 · X1) (BFUN (J)/AFUN (J)) • (1.0D0 · X1)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       BFUN(J) = DHBAR(J) - TBAR(J) - WBAR(J)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             BFUN(J) - DHBAR(J) TBAR(J) - WBAR(J)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   AFGN(S)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           2
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     20
   DOUBLE PREZISTON AFMINIST, PRIMISTS, CP. CTRY(51, 200), DEBAR (51).

L. DHOLDO (51, 200), DEDD (51, 200), DANDMIST, 200), MINTER, MODEL WITHOUT (51, 200), MINTER, 200), WINTER, WINTER, 200), WIN
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       1 IS THE STATION NUMBER SET DOWN FROW THE MAIN PROGRAM
ITER IS A LOCAL ITERATION COUNTR. IT RECORDS THE NUMBER OF
ITERATIONS REQUIRED TO ACHIEVE MASS FLOW CONVERSION OF THIS q-o-
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               VARIABLES INTERNAL TO THE SUBROUTINE ARE: APUN, BPUN, MASFLO, OLDVAZ. TUBPLO, VAZNEM, XI, VMNID
SUBROUTINE VELO (CURV, DH-DO, DEDQ, DVNDH, DWDD, H-SUM, HSTAG, I. AMSTOT, MPRAC, MID. MSTRM, PHI, RADIUS, RHO, TEMP, VELM)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          ITER : 1
IPLD BQ. 6 AND I BQ NSTNS OR.

L. D. DQ. 20 AND I BQ NSTNS) THEN
METERIES, 1 Gel dir VERSION I : 1
WRITELIS, 1 Gel dir VERSION I : 1
WRITELIS, 1 CATA OUTPUT FROM SUBROUTINE VELO: output6 det
WRITELIS, 1 CAURA TERRATION COUNT (FLOM FIELD) IS. COUNT
BNDIR
                                                                                                                                                                                                                                                         THE MENDOWINE INTERCRATES THE RADIAL EQUILIBRING EQUATION TO GET THE MENDOMAL VELOCITY PROPILE THEN CHEKES AND ADJUSTS WHOLD UNTIL CONTINUITY IS SATISSIED FOR THE VELOCITY PROFILE.
                                                                                                                                                                                                                                                                                                                                                               INPUT VARIABLES: CURV, DHODQ, DEDQ, DVNDM, DMHDQ, HOSUM, HSTAG, 1, NAFTAH, PHI, RADIUS, RHO, TEMP,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            INTEGER COUNT, I, ITER, LLIMIT, LP, MLIMIT, NSTEP, NSTRM, MID, TP:P
                                                                                                                                                                                 PROCEDAM VERSION: WHIRL, VARIABLE MALL GEOMETRY, AND CALLINORE'S METHOD OF q-o ITERATION.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       COMMON /CONST/ CP, GANDA, GASCON, GSUBC, NIXCO, PI
XOMOON /CMTRL1/ COUNT, LLINIT, LP, NLINIT, NSTEP
VAHOON /CMTRL2/ RELAXV, RELAXM, TOLM, TOLV, TOLR
                                                                                                                                                                                                                                                                                                                                                                                                                                                                     OUTPUT VARIABLES: VELM, HOSUM, MPRAC
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              WIID = VELM(MID.))
WONID = VELM(MID.))
WO 10 = 1. MSTRN
OLDWR(J) = VELM(J.))**2
CONTHUE
                                                                                                                                gel.dir/velo.f
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           2
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HICH, . 101

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PIND THE NEW CONSTANT OF INTEGRATION (VOMID) AND LINIT THE CHANCE TO WITHIN 400 O'THE OLD VALUE (ABOVE ON BELOW). CHANT AND DINIA 1998 O'THE OLD VALUE (ABOVE ON BELOW). SIGN CHANGES AND RECORDIZE SIGN CHANGES AND RECORDIZE SIGN CHANGES. AND RECORD TO INCREASE. USE THE IF SYNTHENDE BELOW. WINNID NEEDS TO INCREASE. USE THE IF SYNTHENDE BELOW. WINNID NEEDS TO DECREASE. SO WINNID NEEDS TO DECREASE.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          SECANT METHOD SECTION. PROGRAM EXECUTION GETS HERE ONLY AFTER THE FIRST LOCAL ITERATION. WILD, WILD, MIDT), AND DOOTA ARE ALL KNOWN COING INTO THIS SECTION. THIS FIRST PART CONPUTES THE NEXT WMILL TO BE USED IN THE INTEGRATION OF THE RADIAL EQUILIBRIUM EQUATION.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            WHIDE STATE TO OUTDUTE. GAT IF REQUIRED BY LP.
WRITEE LOT 6. OR. LP. EQ. 20) THEN
WRITEEL(5.). MASS FLOW RATE FOR THIS VELOCITY PROFILE...
INASPLO
WRITEEL(6.). MASS FLOW RATE FOR THICE YOUR TREELES...
WRITEEL(6.). VARID FOR NEXT ITERATION .. VARID
WRITEEL(6.).
WRITEEL(6.).
WRITEEL(6.).
                                                                                                                            CHECK CONVERGENCE USING MASS TOLERANCE. TOLA. | 12 CONVERGENCE CONTUTE

THE MASS FLOW FRACTIONS. | 1F NOT. ADJUST VANID AND RE-INTEGRATE.

IF ADDUCT VANID AND RE-INTEGRATE.

IF NOT. ADJUST VANID AND RE-INTEGRATE.

IF NOT. ADJUST VANID AND RE-INTEGRATE.

CALCULATE STREAMTHE MASS FRACTIONS (HUB TO STREAMLINE).

WIFRAC(1, 1) = 0.0000

DO 90 J=2.NSTM

NERAC(3, 1) = TUBFLD(3) / MASFLD + NFRAC(3-1, 1)

90 CONTINUE

GO TO 110
                                                            MASFLO = MASFLO + TUBPLO(J)
IF HALSFLO - LT: 0.000) PRINT*, 'MASFLO ERROR IN VELO', MASFLO CONTINUE
                       HoSUN(I) = HOSUN(I) + TUBFLO(J) + HSTAG(J-1,I))/2.0D0
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              (2.0D0-MASFLO/MASTOT) * VIOLID)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   ELSE
VMNID = DMAXI(0.8D0 • VMNID,
(2.0D0-MASFLO/MASTOT) • VMNID)
                                                                                                                                                                                                                                                                                      PRINT*, ' MASS FLOW DID NOT CONVERGE' IF (MASTOL .LT. 0.0D0) THEN PRINT*, ' ELSE
VELM(J-1,1) * COS(PHI (J-1,1)) 1/2.0D0
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  IF((MASFLO/MASTOT) LE. 1.0D0)THEN VMMID = DMIN1(1.2D0 * VMMID,
                                                                                                                                                                                                                                                                                                                                                                                     IF(ITER .EQ. 1) THEN MOOTH = MASFLO
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  TTER = 1TER + 1
00 TO 15
                                                                                                                                                                                                                                                                                                                                                    PRINT.
                                                                                                                                                                                                                                                                                                                                                                ENDIF
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   100
                                                                                               8
STATION
STATION
STATION
STATION
THE MASS FLOW IN EACH STREAMTUBE AND IS UNDERED FOR THE
STREAMLINE ABOVE IT (TOP BOUNDARY). IT HAS UNITS OF Blug/sec.
MASTLO IS THE VELOCITY PROPILE CALCULATED IN THE PRECEDING SECTION
USING THE VELOCITY PROPILE CALCULATED IN THE PRECEDING SECTION
MASTLO HAS UNITS OF BLUG/sec.
MASTLO IS COMPARED THE TOTAL MASS FLOW (MASTOT) CALCULATED IN
SUBBOUTINE FLOIRT
HOSUM (MASS WEIGHTED STAC SHTMALPY) HAS UNITS OF BLUG (F.2/sec?)
                                                                                CHANE VAZHEM TO VM USING SQUARE ROOT. THIS PREPARES THE DATA
POR PLUM AND CONVENENCE WORK. CHECK FOR NEGATIVE SQUARED VELOCITY.
MRITE THE INTEGRATED VALUES TO OUT DUCE dat IF REQUIRED BY LP.
                                                                                                                                                                                                                                                                                                             DO 50 J.I, NSTRM
IF (WIZNEMIJ) LE. 0.0D0)THEN
PRINT. .....ERROR IN VELO: VELOCITY'2 IS NEGATIVE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      THIS SECTION CALCULATES MASS FLOW, CHECKS CONVERGENCE. ADJUGTS THE MIDGLE STREAMLINE VELOCITY AS NEEDED TO ACHIEVE CONVERGENCE. AND CALCULATES THE MASS AVERAGED STREAMLINE BATHALDY FOR THE CURRENT.
          DO 40 J=1, NSTRM
VICENEN(J) = OLDVILZ(J) + RELAXV + (VICENEN(J) - OLDVILZ(J))
OLDVILZ(J) = VICENEN(J)
CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          DO 80 J=2.NSTRM
TUBFLO(J) = (RMc(J-1,I) + RMc(J,I))/2 0D0 +
TUBFLO(J) = (RADIUS (J,I)**2 - RADIUS (J-1,I)**2) +
( VELM(J,I) * COS(PHI(J,I) +
                                                                                                                                                                                                                                                                                                                                                                                                                                             WRITE(16,*)* J DHBAR AFUN
DO 70 J=WSTRM, LAYTEP
WRITE(16,1003); DHBAR(J), AFUN(J), BFUN(J)
CONTINCE
WRITE(16,*)*
WRITE(16,*)*
WRITE(16,*)*
WRITE(16,*)*
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    CHECKING CONTINUITY
                                                                                                                                                  PRINT: SETTING VN-2 TO 0.010DC VN-2 WARNEW(J) = 0.010D0
                                                                                                                                                                                                                               VELM(J,I) = SORT(VM2NEM(J))
CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          HoSUN(I) = 0.00D0
MASPLO = 0.00D0
TUBPLO(I) = 0.00D0
                                                                                                                                                                   ......
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      PRINT.
                                                                                                                                                                                                                                                                                                                                                                                                  1001
                                                                                                                                                                                                                                           2
                                               9
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TE FLAG EQUALS 1, OR IF THE TERATION COUNTY, MAS NOT EXCEDED THE WITHHUM NUMBER OF PORCED ITERATIONS REQUIRED. ANOTHER ITERATION NUMBER OF PORCED ITERATION SUBJOINED. ANOTHER ITERATION NUMBER OF PORCED ITERATION SUBJOINED.

VELM AND TAKES ON THE NEW VALUES FOUND IN SUBSOITINE VELO.

IFFIAG. EQ. 1 . OR. COUNT . LE. LLINIT) THEN DO 90 IL2. NSTNS DO 90 IL2. NSTNS DO 70 J.1. NSTNW VELM WILL IN STRIM VERM J. I. S. VELNEW J. I. S. CONTINUE

OO CONTINUE

BDD PROPERTY OF A STRIME OF THE STRIME O
                                                                                                                                                                                                                                                                                                                                 RETURN BYO BYO
          VARIABLES INTERNAL TO THE SUBROUTINE ARE: NONE

DOUBLE PRESISTON RADIUS;51, 200), RAIMEN(51, 200), RELAXW, RELAXW,

L TOLM, TOLK, TOLV, VELM(51, 200), VELNEM(51, 200), XX (21, 200)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         WRITE DATA TO FILE IF REQUIRED BY LP
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    DO 40 J11, WETRA

LETUELBA(J.) EQ 0.00, PRINT*.

FLAG IS SET TO 1 IP THE CHANGE IN CONVERGENCE VARIABLE IS GREATER THAN THE TOLERANCE READ IN SUBROUTINE INPUT

FE (ABSCIEDE (J. 1) VELNEM(J. 1) 1 000) GT TOLV)

LET (ABSCIEDE (J. 1) VELNEM(J. 1) 1 000) GT TOLV)

CONTINUE
CONTINUE
                                                                                                                                 CHECK CONVERGENCE OF VELOCITY PIELD. IF THE PIELD HAS NOT COVERGED, THE NEW VELOCITY AND RADIAL LOCATION BECOME THE OLD VELOCITY AND RADIAL LOCATION FOR THE NEXT ITERATION.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                IFILP EQ 8 AND 1 EQ NSTNS)THEN
METTEL18 1)
                                                                                                                                                                                                                                                                                                                                                                                                                      INTEGER COUNT, FLAG, I, LLIMIT, LP, MLIMIT, NSTEP, NSTNS, NSTRM
                                                                                                                                                                                                                      INPUT VARIABLES: NSTRM, NSTNS, RADIUS, RADNEM, VELM, VELNEW
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               COMPARE CHANGE OF VELOCITY FROM THIS ITERATION TO THE LAST:

DO 20 12-13-NSTRM

DO 10 3-1, NSTRM

XX 13. 1 = ABS(VELM(J, 1)/VELNEW(J, 1) · 1 0D0)

CONTINUE

CONTINUE
     SUBROUTINE CONVERT (PLAG. NSTRM. NSTNS. RADIUS, RAINEM.
                                                                                                                                                                                                                                                                                                                                                                                                                                                            COMMON /CNTRL1/ COUNT, LLINIT, LP, NLINIT, NSTEP COMMON /CNTRL2/ RELAXV, RELAXM, TOLM, TOLM, TOLY, TOLR
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   DO 10 J=NSTRM.1, -NSTEP | MITTELLIA.105TNS) | MRTTELLIA.7 J. (VELMICA.1), I=1,NSTNS) | MRTTELLIA.7 J. (VELMICA.1), I=1,NSTNS) | MRTTELLIA.7 J. (XX(J,I), I=1,NSTNS) | MRTTELLIA.7 J. (XX(J,I), I=1,NSTNS) | CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                PRINT: NOM CHECKING VELOCITY CONVERGENCE:
DO 50 1:2, NSTNS
                                                                                                                                                                                                                                                                  OUTPUT VARIABLES: RADIUS, VELA
                                                                                          gal dir/converg.f
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    9
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TF. RULAXATION PACTOR ALREADY HAS A K(min) OF -4.0 INCLUDED (PARABOLIC CONTINUATOR). THE RELAXATION FACTOR DOES NOT CHANGE WITH RADIUS, IT IS A FUNCTION OF q-0 COLY.

RELAX = 1.0DO + (5.0DO/24.0DO) * (1.0DO - AMACH2) *

(RADIOSINSTRM, I) - RADIUS(1,1) / 22DELTA(1) )
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                THE W DIRECTION VELOCITY, VELM, FROM SUBMOUTINE VELO AND ABOUND CREATE A CHUNE THAT IS USED TO PIND THE VELOCITIES THAT CORRESSOND THE NEW ADDIAL LOCATIONS CALCULATED ABOVE. VELNEW CONTAINS THE NEW VELOCITY VALUES.

IF THE NEW RADIAL LOCATIONS CHUNES OF THE HUB AND TIP, THE OFFINIONS ADDIAL LOCATION, RADINGKI, IS SET TO RADIUSALLY THE OFFINIONS ADDIAL LOCATION, RANDRIKKI, IS SET TO RADIUSKI,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    THE INTERPOLATION ROUTINE AND RELAXATION MAY SET THE NEW ENDMALL
RADIAL OUTSIDE THE BOUNDS OF THE INPUT ANNILUS GEOMETRY. TO ELIMINATE
ANY ERRORS, THIS SECTION RESETS THE NEW WALL RADIAL LOCATIONS TO BE
EQUAL TO THE OLD.
RADIAL (STEM, 1) = RADIUS (NSTRW, 1)
RADIAL SEADLY (STEM, 1) = RADIUS (1, 1)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         ** NIM IS 2 WHEN RAINEM FOR THE CURRENT q -> IS COMPARED WITH RADOLD FOR ** THE CURRENT q -> . AN ERROR IN SUBFOUTINE INTER WILL PRINT OUT AN ERROR RESAOR RAING THAT THE ERROR IS DUE TO RADNIN VALUES.
                                                                                                                                                                                                                                                                                                                                                                                                                             CALL INTERP (RADIUS(1,1), VELM(1,1), NSTRM, RADNEW(1,1), VELNEW(1,1), NSTRM, NUM)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             IF (LP EQ. 7 AND I EQ NSTNS OR WRITE (17.1)
WRITE (17.1)
WRITE (17.2)
K (GAWA - CASCON - TEMP (J.1) - GSUBC)
SUM = SUM + MACH2
CONTINUE
AMACH2 = SUM/REAL(NSTRM)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       DO 50 3-1, NSTRM
IF (VELNEW (1, 1) . LE. 0.0000)THEN
PRINT: VELNEW IS ZERO?
PRINT: VELNEW IS ZERO?
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               WRITE(17,*) * 3 RADIUS
WRITE(17,*) * 3 RADIUS
DO 110 J=NSTRM,1, -NSTEP
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                * INTERPOLATING FOR THE NEW VELOCITY
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       ENDIF
                                                                 10
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       50
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      20
   WERECLI JI COMES FROM THE VELOCITY SUBROUTINE VELO. MFRAC CONTAINS
THE FRACTION OF THE FLOW FOR EACH STREAMTUBE AT EACH 4-0. MFRAC AND
RADJUS CREATE A CURGE (RADJUS AS A FUNCTION OF WFRAC) THAT IS USED
TO FIND THE WIRE ADDIAL LOCATIONS THAT MATCH THE INLET STREAM TUBE
MASS FRACTIONS IN MFRAC(J, J)
IP ANY WERAC VALUES ARE OUTSIDE THE BOUNDS OF WFRAC(J, J) OR THE
OPFENDING VALUE, MFRAC(K, I). IS SET TO BE WITHIN WFRAC(K, J)
SUBBOUTINE INFERP

X I OF DATA POINTS THE FOLLOWING PATTERN:
XIN VOUT I OF DATA POINTS

INTERP FINDS YOUT
                                                                                        THIS SUBBOUTINE ADJUSTS THE RADIAL LOCATION AND FINDS THE RADII WHICH CORRESPOND TO THE FIXED STREAMTUBE MASS FRACTIONS
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            CALCULATE THE RELAXATION ROTTOR FOR THE CHANGE IN THE RADIAL
LOCATIONS. RAINER IS UNDER RELAXED. SO THE CHANGE IS SMALLER THAN
MANT WAS CALCULATED BY INTERP.

    MACH2 IS THE SQUARED M-DIRECTION MACH NO. FOR EACH STREAMLINE ALONG
    THE CURRANT q-0. AMACH2 IS THE AVERAGE SQUARED MACH NUMBER FOR THE
    EMTIRE q-0.
    SUM = 0.000
    DO 10.011, NSTRM
    MACH2 = VEIM 1.1 | 1.12/
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          NUM IS I WHEN WEARC FOR THE CURRENT q-o IS COMPARED WITH MFARC FOR THE INLET q-o. AN ERROR IN SUBROUTINE INTERP WILL PRINT OUT AN ERROR MESSAGE SAYING THAT THE ERROR IS DUE TO MFRAC VALUES.

NUM = 1
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           DOUBLE PRECISION ANACHZ, CP, GANDA, GASCON, GSUBC, MACHZ, MRACÍS, 200, MICAO, PI, RADIUGISI, 200), RAINEM (51, 200), RELAX, SIN, TEMP (51, 200), VELM (51, 200
                                                                                                                                                                                     PROGRAM VERSION: WHIRL, VARIABLE WALL GEOMETRY, AND GALLINORE'S METHOD OF q-0 ITERATION.
                                                                                                                                                                                                                                                                                                                                                                   INPUT VARIABLES: I, NDELTA, MPRAC, NSTNS, NSTRM, RADIUS, RDELTA, TEMP, VELM
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         VARIABLES INTERNAL TO THIS SUBROUTINE ARE: AMACH2, MACH2, NUM
   SUBROUTINE RADIAL(I, MFRAC, NSTNS, NSTRN, RADIUS, RADNEW, RDELTA, TEMP, VELM, VELNEW, ZDELTA)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         INTEGER COUNT, I, LLIMIT, LP, MID, MLIMIT, NSTEP, NSTRM, NSTW, NSTW, NUM
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             CALL INTERP(MFRAC(1,1), RADIUS(1,1), NSTRM, MFRAC(1,1), RALNEW(1,1), NSTRM, NUM)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          COMMON /CONST/ CP, GAMMA, GASCON, GSUBC, MIXCO, PI COMMON /CNTRL1/ COUNT, LLINIT, LP, MLINIT, NSTEP
                                                                                                                                                                                                                                                                                                                                                                                                                                                            OUTPUT VARIABLES: RADIUS, RADNEW, VELM, VELNEW
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 INTERPOLATING FOR THE NEW RADII MPRAC(NSTRM, I) = 1.0000
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gal.dir/radial.f

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AT THIS POINT, WE NOW T LAT ALL VALUES OF XIN SHOULD LIE BETWEEN

* XDATALI ) AND XDATA (NDMTA). NEXT THE PROGRAM CALCULATES VALUES FOR

* YOUT USING THE EQUATIONS BELOM.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       IF(XIN(K) GT. XDATA(N) | THEN
IF(N GT. NXY) THEN
IF(N GT. NXY) THEN
PRINT: 'ERROR IN DATA, CAN'T FIND A XDATA VALUE GREATER
4THAN XIN(K) 'K
PRINT' ''
PRINT' ''
            WRITE(17.*) 'NIM INDICATES A PROBLEM WITH WFRAC(1)'
WRITE(17.*) 'THE 'N, 'NASS PRACT IS GRATER THAN'
WRITE(17.*) 'THE TOP VALUE OF THE INLET MASS FRACTION'
WRITE(17.*) 'STATION MASS FRACTION', XIM(K)
WRITE(17.*) 'INLET MASS FRACTION', XIM(K)
                                                                                                                                                                                                                                                                                                                                                                                     WRITE(17.*) 'NUM INDICATES A PROBLEM WITH RADNEW'
WRITE(17.*) 'THE ', K, 'RADIUS IS GREATER THAN THE'
WRITE(17.*) 'THE WALL RADIUS VALUE'
WRITE(17.*) 'RADNEM', XIN(K)
WRITE(17.*) 'TIP RADIUS', XDATA(K)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           XIN(K) > XDATA(2), SO FIND A XDATA VALUE THAT IS > XIN(K) IF NO VALUE CAN BE FOUND, SOMETHING IS VERY WRONG WITH THE DATA IN N = 3
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          YOUT(K) = ((KIN(K) - XDATA(N-1)) * (KIN(K) - XDATA(N))) * (XDATA(N-2) - XDATA(N-1)) * (XDATA(N-1)) * (XDATA(N-2) - XDATA(N)) * (XDATA(N-2) - XDATA(N-2) * (XDATA(N-2) - XDATA(N)) * (XDATA(N-2) - XDATA(N-2) * (XDATA(N-2) * (XDATA(
                                                                                                                                                                                                                   PRINT*, 'THE ', K, ' RADIUS IS GREATER THAN THE' PRINT*, 'TIP WALL KADIUS VALUE' PRINT*, 'RADINE' XIN(K) PRINT*, 'TIP RADIUS', 'XDATA(K)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        WRITE(1).1004) 'K ± ', K, 'XIN = ', XIN(K)
PORAT(1X, A4, IZ, 2X, A6, P14.12)
WRITE(17.1) ' '
CO TO 22
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            XIN(K) = XDATA(K)
ENDIF
ENDIF
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                ENDIA
PRINT*,
WRITE(17.*)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 WRITE
OD TO
ENDIF
N = N+1
OO TO 10
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           1004
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           9
DOUBLE PRECISION XDATA (NDATA), YDATA (NDATA), XIN (NXY), YOUT (NXX)
1275-058 NDATA, KNY, KNY
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   CHECK POR VALID DATA. ALL XIN VALUES MOST BE WITHIN THE RANGE OF THE XDATA VALUES. VALUES OUTSIDE THE RANGE OF XDATA ARR RESET TO THE ROLD VALUE OO YOUNGS. VALUES OUTSIDE THE RANGE OF XDATA ARR RESET TO THE ROLD VALUES OF XDATA. THE PRST PART OF THE IF STATEMENT TAKES CARE OF ANY XIN < XDATA(I), THE SECOND PART (ELSE) IS FOR ANY XIN < XDATA(HDATA).
                                                          THIS SUBBOUTINE USES LAGRANGIAN INTERPOLATING POLYNOMIAL METHOD TO PIND A Y VALUE FOR ANY GIVEN. Y VALUE. THIS SUBBOUTINE SHOULD WORK FOR ANY VERSION OF FIRE PROGRAM. YDATA, YDATA, AND NDATA CREATE A 2-DIMENSION CURVE OF WARTA POINTS. XIN IS HALF THE DATA FOR A CURVE OF NAY POINTS. INTERPOLATES FOR THE YOUT DATA.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             IF(XIN IK) .GT. XDATA(NDATA))THEN
PRINT, ......FREPOLATION
FINE.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                IFUND. EQ. 1) THEN THEN THE STATION MASS FRACTION IS LESS THAN PRINT. THE "THE BOTTOM VALUE OF THE INLET MASS FRACTION" PRINT", STATION MASS FRACTION", XINIS, PRINTS FRACTION", XINIS, PRINTS, "INLET MASS FRACTION", XINIS,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    TE (MM EQ. 1) THEN
IPPLIME TO ALC PEACTION IS GREATER THAN'
PRIME THE TOP VALUE OF THE INLET MASS FRACTION'
PRIME THE STRITION MASS FRACTION'
PRIME THATE STRITION MASS FRACTION'
PRIME THATE THAN STRACTION'
AND THATE THAN STRACTION'
AND THAN STRAC
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    IS.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               20 K=1,NXY
IF(XIN[K] ...T. XDATA(1)) THEN
BRUTTNE. .....ERROR IN DATA SENT TO INTERPOLATION
        SUBROUTINE INTERP(XDATA, YDATA, NDATA, XIN, YOUT, NXY, NUM;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             WRITE(17.*) NUM INDICATES A PROBLEM WITH RADNEW WRITE[17.*) THE: K. KADIUS IS LESS THAN THE TRITE(17.*) THUB MALL RADIUS VALUE' WRITE(17.*) RADNEW 'X KIN(K) WRITE(17.*) HUB RADIUS 'X XDATA(K)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  ELSE
PRINT, THE , K, AADIUS IS LESS THAN THE PRINT, ALDEN ALLE ADDIUS VALUE
PRINT, ALDEN , XINIK)
PRINT, HE ADDIUS , XDATAIK)
                                                                                                                                                                                                                                                                                                                                                                INPUT VARIABLES: XDATA, YDATA, NDATA, XIN, NXY, NUM
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 VARAIBLES INTERNAL TO THE PROGRAM ARE: NONE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         XIN(K) = XDATA(K)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                OUTPUT VARIABLES: YOUT
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          PRINT*
                                                                                                   gal.dir/interp.f
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                ELSE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                8
```

((XIN(K) - XDATA(N-2)) \* (XIN(K) - XDATA(N))) \*
YDATA(H-1)/ (XINTA(N-1)) \*
((XINTA(N-1) - XDATA(N)) \*
((XINTA(N-1) - XDATA(N))) \*
((XINTA(N-1) - XDATA(N))) \*
((XINTA(N-1) - XDATA(N-2)) \* (XIN(K) - XDATA(N-1))) \*
(XDATA(N) / (XDATA(N-1)) \*

E E E E 20 COMPINUE 21 RETURN 22 END

```
IF PLAG EQUALS 1, OR 1P THE ITERATION COUNTER (COUNT) HAS NOT EXCEEDED THE MINIMUM MINBER OF PORCED ITERATIONS REQUIRED. AMOTHER ITERATION MUST BE EXCUTED. SINCE THE FLOM FIELD HAS NOT CONVERGED.

VELIA AND RADIUS TAKE ON THE NEW VALUES FOUND IN SUBROUTINE redial DO 90 12.2, NSTR

DO 90 12.2, NSTR

DO 10.21, NSTR

DO 10.21, NSTR

NVELM (J. 1) = VELNIM (J. 1)

RADIUS (J. 1) = RADNEW (J. 1)

RADIUS (J. 1) = RADNEW (J. 1)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       CONTINUE
        20
        7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.75 4 7.
                                              gal.dir/converg.f
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            VARIABLES INTERNAL TO THE SUBROUTINE ARE: NONE

DOUBLE PRESISTON RADIUS(51, 200), RAINEN(51, 200), RELAXW, RELAXW,

TOLM, TOLM, TOLV, VELM (51, 200), VELNEM(51, 200), xx (21, 200)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         PLAG IS SET TO 1 IF THE CHANGE IN CONVERGENCE VARIABLE IS GREATER THAN THE TOLERANCE READ IN SUBROUTINE INPUT

IF (ABS(RADIUS(J, 1) / RAINEM(J, 1) - 1.000) .GT. TOLR) FLAG = 1
CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     INTEGER COUNT, FLAG, I, LLIMIT, LP, MLIMIT, NSTEP, NSTWS, NSTRM
                                                                                                                                                                                     CHECK RADIAL CONVERGENCE. IF THE FIELD HAS NOT COVERGED, THE NEW VELOCITY AND RADIAL LOCATION BECOME THE OLD VELOCITY AND RADIAL LOCATION POR THE NEXT ITEMS SUBROUTINE SHOULD WORK POR ANY VERSION OF THE PROGRAM.
                                                                                                                                                                                                                                                                                                                                                                  INPUT VARIABLES: NSTRM, NSTNS, RADIUS, RAINEM, VELNEW
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   CHECK CONVERGENCE OF CHANGE OF STREAMLINE RADIAL LOCATIONS
DO 10 12-1 NSTNS
DO 10 12-1 NSTNS

XX(1,0.11) = ABS(RADIUS(3,1)/RADNEW(3,1) - 1.0D0)
O CONTINUE
SUBROUTINE CONVERS (FLAG, NSTRM, NSTNS, RADIUS, RAINEM, & VELM, VELNEM)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         COMMON /CNTRL1/ COUNT, LLINIT, LP, NLINIT, NSTEP COMMON /CNTRL2/ RELAXV, RELAXW, TOLM, TOLM, TOLY, TOLR
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   DO 30 J=NSTRM, 1, -NSTEP
WRITE(18,*) J, (RADIUS(J,I), I=1,NSTNS)
WRITE(18,*) J, (RADNEW(J,I), I=1,NSTNS)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           DO 40 J.1, NSTRM
IP(VELNEW(J.1) - EQ. 0.00) PRINT*,
'VELNEW(J.1) ERPOR IN CONVERG', J, I
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           PRINT*, ' NOW CHECKING RADIAL CONVERGENCE'
DO 50 1=2, NSTNS
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 MRITE(18,*) J, (XX(J,I), I=1,NSTNS)
MRITE(18,*)
CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                     OUTPUT VARIABLES: RADIUS, VELM
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          22
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          9
```

```
CLOSE(112)
CLOSE(113)
CLOSE(114)
CLOSE(115)
CLOSE(115)
CLOSE(117)
CLOSE(117)
CLOSE(117)
CLOSE(117)
                                                                                                                                                                                                                                                                                                                                                                                 1015 FORMAT(1X, 12, 1X, 10(E10.4, 2X))

***CHECK CONSERVATION OF ANGULAR MOMENTUM output written to output 9.det

**D 66 1=1,NSTNS

***DETAILS TRADIUS(INSTR.1) - RADIUS(1,1)

***SPAN(1) = RADIUS(1,1)

***DOTO FOR TRADIUS(1,1)

***DOTO FOR TRADIUS(1,1)

***ROBAT(3,1) = (RADIUS(3,1) - RADIUS(1,1))

***SPAN(1) = (RADIUS(3,1) - RADIUS(1,1))

***SPAN(1) = 2 VEL (NID,1) - 2 LOC(1)

***SPAN(1) = 2 VEL (NID,1) - 2 LOC(1)

***SPAN(1) = 2 VEL (NID,1) - 2 LOC(1)

***SPAN(1) = 2 VEL (NID,1) - 2 LOC(1) - 2 LOC(1)

***SPAN(1) = 2 VEL (NID,1) - 2 LOC(1) - 3 RED(1,1)
                                                1013 FORMAT(1X, IZ, 1X, 10[F7.3, 2X))
                                                                                                                                                                                                240 CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          DO 67 J=NSTRH,1,-1
WRITE(19,1002) X(J,1), RADRAT(J,1),
X(J,NSTNS), RADRAT(J,NSTNS)
WRITE(21,1013) J, (PDELTA(J,1)/144.0D0, I=1,NSTNS,ISTEP)
220 CONTINUE
                                                                                                                                           WRITE(21,*) '
WRITE(21,1013) J, (TSTAG(J,I), I=1,NSTNS,ISTEP)
                                                                                                                                                                                                                                                                                                             WRITE(21,*)

WRITE(21,*)

THE HEAT TRANSPER COEFFICIENT IS:
DO 260 J=NSTRM, 1.-NSTEP

WRITE(21, 1015) J. (HTCOEF (J, 1), I=1,NSTNS, ISTEP)
                                                                 WRITE(21,*)
WRITE(21,*)
WRITE(21,*)
WRITE(21,*)
WRITE(21,*)
THE STANIC TEMPERATURE FIELD (R) IS:
DO 230 J-HSTRM 1, -NSTEP
CONTINUE (21,1013) J, (TEMP(J,1), I=1,NSTNS,ISTEP)
CONTINUE
                                                                                                                                                                                                                                  67 CONTINUE
1002 PORMAT(1X, F6.4, 2X, F5.3, 6X, F6.4, 2X, F5.3)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             WRITE(19,*) **
WRITE(19,*) **
WRITE(19,*) REYN(NSTNS)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 CONTINUE
                                                                                                                                                                                                                                                                                                                                                                   260 CONTINUE
                                                                                                                        230
                                                                                                                                                                                                                                                                                             250
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   9 9
        1007 FORMATIX, 12, 1X, 10(F6.3, 1X))
                                                                                                                                                                                                                                                                                                                                 1009 FORMAT(IX, 12, 1X, 10(E10.4, 2X))
                                                                                                                                                                                                                                                                                                                                                                                                                                        1011 PORNAT(1X, IZ, IX, 10(E10.4, ZX))
                                                                                            WRITE(21,*) ' '
WRITE(21,*) ' ' THE 2-DIRECTION VISCOUS BODY FORCE (1bf/ft^3) IS:'
DO 110 J=NSTRM,1,-NSTEP
CONTINUE
CONTINUE

WRITE(21,1009) J, (EZ (J,1), I=1,NSTNS,ISTEP)
                                                                                                                                                                        WRITE(21.*) ' ' ' WRITE(21.*) ' THE THETA DIRECTION BODY FORCE (1bf/ft^3) IS:' DO 120 J=NSTMU1.-NSTEP WRITE(21.1009) J, (ETHETA(J,I), I=1.NSTMS,ISTEP) CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 MRITE(21.*) . CHANGE IN PRESSURE PROW THE INLET (ps;) . WRITE(21.*) . INCREASE IS POSITIVE, DECREASE IS NEGATIVE. DO 220 5-NSTRM ). HSTEP
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  WRITE(21.*) '
WRITE(21.*) '
THE STATIC PRESSURE FIELD (psi) IS: '
DO 170 J.HSTRW 1, HSTEP
WRITE(21.1013) J, (PRESS(J.I)/144.0, I=1,NSTNS.ISTEP)
CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                           HRITE(21,*) ' '
HRITE(21,*) ' '
HRITE(21,*) ' THE STACHATION PRESSURE PIELD (pai) IS: '
DO 160 J=NSTRM, 1.-NSTEP
CONTINUE
CONTINUE
CONTINUE
                                                                                                                                                                                                                                               WRITE(21,*) ''WRITE(21,*) ''THE DISSIPATION FUNCTION (1bE/fc-2) IS:'DO 130 J-MSTEM, 1.-MSTEP WRITE(21,*) 'ITHE DISSIPATION FUNCTION (1bE/fc-2) IS:'DO 130 J-MSTEM, 1.-MSTEP CONTINUE (11,1009) J. (DISSIP(J,1), I=1,MSTMS, ISTEP)
     MRITE[2],*)'',
MRITE[2],*)''THE STREAMLINE CURVATURES (1/ft) ARE:'
DO 100 JENSTRW.1,-NSTEP
WRITE[21,1007)'J' (CURV(J,I), I=1,NSTNS,ISTEP)
GONTINUE
                                                                                                                                                                                                                                                                                                                                                              WRITE(21,*)

WRITE(21,*)

WRITE(21,*)

DO 150 Jandyra, 1.-NSTRP

WRITE(21,1011) J. (RHO(J,1), I=1,NSTNS,ISTEP)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          DO 210 11, NSTNS
DO 200 J-1, NSTNN
POELINA(J, I) = PRESS(J, I) - PRESS(J, I)
CONTINUE
CONTINUE
CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                       CONTINUE
                                                                                                                                                       110
                                                                                                                                                                                                                                                                                                      130
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             99
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         200
                                                                                                                                                                                                                              120
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             170
```

```
1005 FORMATIX, 10(E10.4, 2x))
WRITE(21,1001) J, (2VEL(J,I), I=1,NSTNS,ISTEF)
CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     WRITE(21,*) . . .
                                  20
                                                                                                                                                                                                        30
                                                                                                                                                                                                                                                                                                                                                                              6
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       20
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             9
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          20
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      80
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               8
         THIS SUBBOUTINE PRINTS THE OUTPUT FOR THE WHIRL VERSION

VARIABLES INTERNAL TO THIS SUBBOUTINE ARE: NONE

DOUBLE PRECISION CP, CURV(51,200) DISSIP(51,200), ENTHAL(51,200),

ENTHAL(51,200), EX(51,200), ENTHOSIS, ENTHAL(51,200),

MENC(51,200), MIXCO, MIXTO, MIXTO
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           MRITE(2), 1
MRITE(
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        1000 FORMAT(1X, 12, 1x, 10(F6.3, 2X))
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    INTEGER COUNT, ISTEP, LLIMIT, LP, MID, MLIMIT, NSTEP, NSTRM, NSTNS
                                                                                                                                SUBROUTINE OUTPUT(CURV, DISSIP, ENTHAL, ENTROP, EZ, ETHETA, HOSIM, HETA, HYOSE, MASTOT, NID, WERAC, MAT, NSTRM, NSTRM, PHI, PRESS, PSTRAC, BADIUS, RHO, FVEL, TEMP, TSTAG, VELTOT, VELM, VTHETA, ZLOC, ZVEL)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     WRITE(21,*) 'ITERATION LIMIT REACHED. PROGRAM UNCONVERGED:
WRITE(21,*) 'MAX ITERATION LIMIT; ', MLIMIT
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    BNDIP ... ALL DIMENSIONS IN ft, sec, 1bf, R UNLESS NOTED
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     IF(COUNT .LT. MLINIT) THEN WRITE(21,*) 'ITERATIONS TO REACH CONVERGENCE: ', COUNT
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               WRITE(21.*)
WRITE(21.*)
WRITE(21.)
WRITE(21.)
WRITE(21.)
THE RADIAL LOCATIONS (inches) ARE:
DO 10 J=NSTRM,1.-NSTRP
WRITE(21.1000)J, (RADIUS(J,1)*12.0D0, I=1.NSTNS,ISTEP)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      COMMON / CONST/ CP, GANNA, GASCON, GSUBC, MIXCO, PI COMMON / CAPTRL1/ COUNT, LLINIT, LP, MLINIT, NSTEP
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      WRITE(21,*) ' ' '
MRITE(21,*) ' ' '
WRITE(21,*) ' 'HE AXIAL VELOCITIES (ft/sec) ARE: '
DO 20 JHNSTRH,', NSTEP
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             WRITE THE VELOCITY OUTPUT
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         ISTEP = 1
IP(NSTNS .GT. 20)THEN
ISTEP = 4
ENDIP
                                                                                                                                                         output.f
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            9
```

1003 FORWAT(1X, 12, 1X, 10(E10.4, 2X)) WRITE(21.\*)
WRITE(21.\*)
WRITE(21.\*)
WRITE(21.\*)
WRITE(21.\*)
WRITE(21.1005) (HoSUM(I). I=1.NSTNS.ISTEP) . : 51 WRITE(21.\*) ' WRITE(21.\*) ' THE STAGNATION ENTHALPY FIELD (ft.2/sec.2) BD 80 J.NSTEW.1, NSTEP WRITE(21.1) ' (HSTAG(3.1), 1=1,NSTNS, ISTEP) WRITE(21.1003) J, (HSTAG(3.1), 1=1,NSTNS, ISTEP) WRITE(21.\*) ' WRITE(21.\*) ' WRITE(21.\*) ' THE STATIC ENTHALPY FIELD (£t~2/\*ec~2) : DO 70 J\*NSTRM.1. NSTEP CONTINUE (J.1), I=1.NSTNS.ISTEP) WRITE(21.\*)
WRITE(21.\*) WRITE(21.\*) ' THE ENTROPY FIELD (ft.2/sec.2 R) 18:'DO 90 J=NSTRM,1.NSTEP PROPOSED (1), I=1,NSTRE) GNTTOPED (3,1), I=1,NSTRS,[STEP) CONTINUE WRITE(21,\*)

WRITE(21,\*)

WRITE(21,\*)

WRITE(21,\*)

WRITE(21,\*)

WRITE(21,1001)

WRITE(21,1001)

WRITE(21,1001)

WRITE(21,1001) WRITE(21,\*)

WRITE(21,\*)

WRITE(21,\*)

THE TOTAL VELOCITIES (ft/sec) ARE:

DO 60 J=NGTRM, 1.-NSTEP

CONTINUE

CONTIN WRITE(21.\*)
WRITE(21.\*)
WRITE(21.)
WRITE(21.)
WRITE(21.)
WRITE(21.1001) J. (RVEL(J.1). I=1.NSTNS.ISTEP)
CONTINUE 1001 FORMAT(1X, 12, 1X, 10(F10.4, 2X))

CLOSE(21) RETURN END

### APPENDIX D. RESULTS FOR EXAMPLE PROBLEMS

Appendix D contains the full program output for the two example problems described in Chapter 4.

## INPUT DATA FOR CYCLOIDAL CONVERGING NOZZLE WITH NO WHIRL

UNLESS NOTED Œ DATA PROM THE INPUT SUBROUTINE ALL DIMENSIONS ARE IN ft. sec, lbf.

ft^2/sec^2 R slug ft/lbf sec^2 ft^2/sec^2 R THE CONSTANTS USED ARE:

CASCON: 1715, 84000000000
GSUET: 1.000000000000
CP.E: 5.000 0.70000000000
GAMMA: 1.40000000000000
PI: 3.141592653589793

LOCALLA LOCALLA LOCALLA LOCALLA LOCALA LO ADDIUS 1.0000 1.0000 0.9167 0.9150 0.9333 0.7500 0.7500 0.7667 0.7683 0.6657 0.6657

CALCULATION PROGRAM

GLOBAL ITERATIONS TO REACH CONVERGENCE: UNIVERSAL ITERATIONS TO CONVERGENCE: ALL DIMENSIONS IN ft. eec. lbf. R UNLESS

0.4900552816037199

ANNULUS:

RATE FOR THE

FLOW

MASS

5000 10.573 10.371 10.167 9.961 9.752 9.752 9.325 9.107 8.885 8.659 10.960 10.960 10.6687 10.6687 10.6687 10.6688 111.54 111.154 10.756 10.352 9.942 9.528 9.112 8.280 7.867 L LOCATIONS (inches) ARE: 11.99 11 27 11.77 11.49 11.49 11.40 11.33 11.65 10.85 10.85 10.85 10.89 10.8 IONS 1. DIRECTION 0.50 E RADIAL 11.0000 11.0000 10.00000 10.0000 10.0000 10.0000 10.0000 10.0000 10.0000 10.0000 10.0 

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THE STATIC ENTHALPY FIELD (ft.2/sec^2) 19:

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0.3092E+07 0.3090E+07 0.3090E+07 0.3090E+07 0.3090E+07 0.3090E+07 0.3090E+07 0.3090E+07 0.3090E+07	0.31246.07 0 0.312386.07 0 0.312386.07 0 0.312386.07 0 0.312286.07 0 0.312386.07 0 0.312386.07 0 0.312386.07 0	0.2444444444444444444444444444444444444	.1528E+07 0.1		1.6800E-01 0.34970E-03 0.1005E-01 0.1446E-01 0.145E-01 0.145E-01 0.145E-01 0.6873E-02 0.6973E-02
0.3032E+07 0.3031E+07 0.3031E+07 0.3031E+07 0.3031E+07 0.3031E+07 0.3031E+07 0.3031E+07	0.3124 E+077 0.3128 E+077 0.3128 E+077 0.3123 E+077 0.3123 E+077 0.3123 E+077 0.3123 E+077 0.3123 E+077 0.3123 E+077	0 0 2 2 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4	1528E+07 0.		. 6038E-01 . 5140E-01 . 5140E-01 . 650E-01 . 44195E-01 . 3976E-01 . 3090E-01
0.3095E+07 0.3094E+07 0.3094E+07 0.3094E+07 0.3094E+07 0.3094E+07 0.3094E+07 0.3094E+07	0.3124E+07 0.3123E+07 0.3123E+07 0.3123E+07 0.3123E+07 0.3123E+07 0.3123E+07 0.3123E+07	0.244488.05 0.244488.05 0.244488.05 0.244488.05 0.24448.05 0.24448.05 0.24448.05 0.24448.05 0.24448.05 0.24488.05	0.1527E+07 0.	666 0.466 800 0.290 99 0.139 03 0.139 04 0.139 05 0.139 07 0.007 087 0.130 883 0.036 66 0.376	2311E 00 3380E 00 3380E 00 4133E 00 4136E 00 -4116E 00 -3103E 00 -3103E 00 -3103E 00 -3103E 00 -3103E 00 -3103E 00 -3103E 00
0.3101E+07 0.3100E+07 0.3100E+07 0.3100E+07 0.3100E+07 0.3100E+07 0.3100E+07 0.3100E+07 0.3100E+07	0.3124E.07 0.3123E.07 0.3123E.07 0.3122E.07 0.3122E.07 0.3123E.07 0.3123E.07 0.3123E.07	00.244444444444444444444444444444444444	.1525E+07 0.3	2.5488 0.0568 0.	4367E.00 6555E.00 6555E.00 7827E.00 7937E.00 7937E.00 7937E.00 7937E.00 7937E.00 7937E.00 7937E.00 7937E.00 7937E.00
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0.3118E+07 0.3118E+07 0.3118E+07 0.3118E+07 0.3118E+07 0.3118E+07 0.3118E+07 0.3118E+07	ENTHALPY FI 3123E+07 3123E+07 3123E+07 3123E+07 3123E+07 3123E+07 3123E+07 3123E+07 3123E+07 3123E+07	PLD (#F.2/8	STAGNATION EN 1529E+07 0.1	CURVATURES 2.5548 1.394 - 3.19 1.318 - 2.10 0.285 - 0.13 0.285 - 0.13 0.13 0.13 0.13 0.13 0.13 0.13 0.13	N VISCOUS BO 7872E 02 573E 02 573E 02 573E 02 135E 02 135E 02 135E 02 135E 02 1249E 02 1249E 02 1249E 02 1359E
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THE THETA DIR. 10 0.0000E.00 9 0.0000E.00 7 0.0000E.00 7 0.0000E.00 5 0.0000E.00 6 0.0000E.00 1 0.0000E.00 1 0.0000E.00	THE DISSIPATE 11 0.0000E-00 10 0.0000E-00 9 0.0000E-00 7 0.0000E-00 5 0.0000E-00 10 0.0000E-00 10 0.0000E-00 10 0.0000E-00 10 0.0000E-00 10 0.0000E-00	THE DENSITY F. 11 0.23642-0.2 9 0.23642-0.2 9 0.23642-0.2 9 0.23642-0.2 6 0.23642-0.2 6 0.23642-0.2 1 0.23642-0.2	THE STAGNATION 11 11 14 700 14 10 14 700 14 10 14 700 14 7 14 700 14 5 14 700 14 5 14 700 14 1 14 700 14	THE STATIC PRE 11 14:618 14:61

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		0.2773E-03 0.2775E-03 0.2775E-03 0.2775E-03 0.2775E-03 0.2775E-03 0.2775E-03	0.1667E+01 0.1667E+01 0.1667E+01 0.1667E+01 0.1667E+01 0.1667E+01 0.1667E+01 0.1667E+01 0.1667E+01 0.1667E+01
		0.2775E-03 0.2776E-03 0.2776E-03 0.2776E-03 0.2776E-03 0.2776E-03 0.2776E-03 0.2776E-03	0.1667E+01 0.1668E+01 0.1668E+01 0.1668E+01 0.1668E+01 0.1668E+01 0.1668E+01 0.1668E+01 0.1668E+01 0.1668E+01
00000000000000000000000000000000000000	519,940 519,940 519,671 519,661 519,660 519,661 519,654 519,654 519,654	0.2783E-03 0.2784E-03 0.2784E-03 0.2784E-03 0.2784E-03 0.2784E-03 0.2784E-03 0.2784E-03	0.1672E+01 0.1673E+01 0.1673E+01 0.1673E+01 0.1673E+01 0.1673E+01 0.1673E+01 0.1673E+01
00000000000000000000000000000000000000	119.914 119.631 119.668 119.668 119.668 119.661 119.66	0.27978-03 0.27988-03 0.27988-03 0.27988-03 0.27988-03 0.27988-03 0.27988-03 0.27988-03	0.1681E.01 0.1681E.01 0.1681E.01 0.1681E.01 0.1681E.01 0.1681E.01 0.1681E.01 0.1681E.01 0.1681E.01
	519 6869 519 6869 519 6665 519 6661 519 666 519 664 519 664 519 664 519 673 519 673	0.2812E-03 0.2812E-03 0.2812E-03 0.2812E-03 0.2812E-03 0.2812E-03 0.2812E-03 0.2812E-03 0.2812E-03	0.1689E.01 0.1699E.01 0.1690E.01 0.1690E.01 0.1690E.01 0.1690E.01 0.1690E.01 0.1690E.01 0.1690E.01
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1004 - 0 183 1004 - 0 183	64 67 67 67 67 67 67 67 67 67 67 67 68 68 68 68 68 68 68 68 68 68 68 68 68	28306E-03 28306E-03 28306E-03 28306E-03 28306E-03 28306E-03 28306E-03 28306E-03 28306E-03	1701E+01 1701E+01 1701E+01 1701E+01 1701E+01 1701E+01 1701E+01 1701E+01 1701E+01
9999999999	668 519 667 668 519 667 668 519 667 668 519 667 667 668 519 667 668 519 667 668 519 667 668 519 668 51		
15. No. 10. 10. 10. 10. 10. 10. 10. 10. 10. 10	(R) IS: 6675 519.6 6669 519.6 6670 519.6 670 519.6 670 519.6 670 519.6 664 519.6	03 0.2834 03 0.2834 03 0.2834 03 0.2834 03 0.2834 03 0.2834 03 0.2834 03 0.2834	01 0.1703 01 0.1703 01 0.1703 01 0.1703 01 0.1703 01 0.1703 01 0.1703 01 0.1703 01 0.1703
No.000000000000000000000000000000000000		IS: 28.7E-03 0.28.7E-03 0.28.7E-03 0.28.7E-03 0.28.7E-03 0.28.7E-03 0.28.7E-03 0.28.7E-03 0.28.7E-03 0.28.7E-03	1ENT 1S: 0.1705E+01 0.1705E+01 0.1705E+01 0.1705E+01 0.1705E+01 0.1705E+01 0.1705E+01 0.1705E+01 0.1705E+01
000111V	100 TEMPERATURE 7 519 670 519 671 519 670 519 670 519 670 519 670	VISCOSITY 1 0.2837E-03 0.2837E-03 0.2837E-03 0.2837E-03 0.2837E-03 0.2837E-03 0.2837E-03 0.2837E-03	SFER COEFFICIES 0.1705E-01 0.1705
1 1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	E STACHOLON (199 670 519 670 519 519 670 519 519 670 519	TURBULENT 2837E-03 2837E-03 2837E-03 2837E-03 2837E-03 2837E-03 2837E-03 2837E-03	THE HEAT TRANSFER 11 0.1705E-01 0.1 19 0.1705E-01 0.1 10 0.1705E-01 0.1 10 0.1705E-01 0.1 10 0.1705E-01 0.1 10 0.1705E-01 0.1
	F 10 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	# 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	H 10 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

# INPUT DATA FOR PREE VORTEX WHIRL VELOCITY CONSTANT HUB AND CASING SHAPE

	pei R in	0.5000000000000000 0.500000000000000 0.499999999999996	
NOTED	2116.800000000000000000000000000000000000	0.50000 0.50000 0.499999	21 1.00000000000000000000000000000000000
16f. R UNLESS	LET: 2116. ET: 519.67 000000000000000000000000000000000000	0.500000000000000000000000000000000000	21 1S (q-o) IS: 1.0000000 1.00000000000000000000000000
UT SUBROUTINE E IN ft. sec.	ON TRMP AT INI INLET: 0.00	9	EAMLINES IS: PUTING STATION ERANCE USED IS TOLERANCE IS: ON FACTOR USEI
DATA FROM THE INPUT SUBROUTINE ALL DIMENSIONS ARE IN (t. sec. lb(, r unless noted)	CONSTANT STAGNATION PRESS AT INLET: 2116.80000000 CONSTANT STAGNATION TRUE TINLET: 519.67000000000000000000000000000000000000	0.000000000000000000000000000000000000	THE NUMBER OF STREAKLINES IS: THE NUMBER OF COMPUTING STATIONS (q-o) IS: THE MASS FLOW PUBLENANC BYED IS: 1.00000000 THE RADIAL CHANGE TOLERANCE IS: 1.00000000 VELOCITY RELAXATION FACTOR USED: 0.300000
Y T	NOOTH !	0000	SHT SHT JE

### PROGRAM CALCULATION SUMMARY ARBITARARY WHIRL DISTRIBUTION PROGRAM VARIABLE WALL GEOMETRY

GLOBAL ITERATIONS TO REACH CONVERGENCE:
UNIVERSAL ITERATIONS TO CONVERGENCE:
ALL DIMENSIONS IN ft. sec. lbf, R UNLESS NOTED

MASS PLOW RATE POR THE ANNULUS: 0.3301385378064700

THE

	100.0023 100.0023 100.0023 100.0023
10.000 10.000 9.000 9.000 1.000 8.000 7.000 7.000 6.000 6.000	0023 0023 0023
10.000 9.000 8.000 7.000	100.
10.000 9.000 18.000 7.000 6.000	100.0023 100.0023 100.0023 100.0023
10.000 9.000 8.000 7.000 6.000	0023 1 0023 1 0023 1
10.000 9.000 8.000 7.000 6.000	1000.000
10.000 9.000 7.000 6.000	100.0023 100.0023 100.0023 100.0023
10.000 9.000 7.000 6.000	23333
9.000 7.000 6.000	23 100.0023 1 23 100.0023 1 23 100.0023 1 23 100.0023 1
LOCATIONS (inches) ARE: 10.000 10.000 10.000 8.000 8.000 9.000 7.000 7.000 7.000 6.000 6.000	40000
ACATIONS 10.000 J 9.000 J 7.000	AXIAL VELOCITIES (100.00100.0007 100.000100.0001100.0001100.0001100.0001100.001
THE RADIAL L 21 10.000 1 16 9.000 6 7.000 1 6.000	AXIAL VE 100.000 100.000 100.000
174E 21 1 116 117 117 117	114E

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100.0023	0.0000 0.0000 0.0000	100.0023 100.0019 100.0023 100.0057	7.2055 8.0072 8.9732 10.2852 12.0392	100.2615 100.3223 100.4041 100.5298	0.3118E+07 0.3118E+07 0.3118E+07 0.3118E+07 0.3118E+07	0.3123E+07 0.3123E+07 0.3123E+07 0.3123E+07 0.3123E+07	0.2444E+05 0.2444E+05 0.2444E+05 0.2444E+05	.1031E+07	
100.0023	000000	100.0023 100.0023 100.0023 100.0055 100.0055	7.2053 8.0069 8.9750 10.2800	100.2615 100.3223 100.4042 100.5293	0.3118E+07 0.3118E+07 0.3118E+07 0.3118E+07 0.3118E+07	0.3123E+07 0.3123E+07 0.3123E+07 0.3123E+07 0.3123E+07	0.2444E+05 0.2444E+05 0.2444E+05 0.2444E+05 0.2444E+05	031E+07 0	
100.0023	00.0000 0.00000 0.00000	100.0023 100.0021 100.0023 100.0023 100.0053	7.2051 8.0066 8.9771 10.2741	100.2615 100.3223 100.4044 100.5287	0.3118E+07 0.3118E+07 0.3118E+07 0.3118E+07 0.3118E+07	0.3123E+07 0.3123E+07 0.3123E+07 0.3123E+07 0.3123E+07	0.2444E+05 0.2444E+05 0.2444E+05 0.2444E+05 0.2444E+05	.1031E+07 0.1	00000
100.0023	0.0000 0.0000 0.0000 0.0001	100.0023 100.0023 100.0021 100.0052 100.0052	7.2047 8.0061 8.9796 10.2677 12.0324	100.2615 100.323 100.4046 100.5280	0.3118E+07 0.3118E+07 0.3118E+07 0.3118E+07 0.3118E+07	0.3123E+07 0.3123E+07 0.3123E+07 0.3123E+07 0.3123E+07	0.2444E+05 0.2444E+05 0.2444E+05 0.2444E+05 0.2444E+05	.1031E+07 0.1	000000000000000000000000000000000000000
100.0023	000000000000000000000000000000000000000	100.0024 100.0022 100.0023 100.0050	7.2043 8.0056 8.9825 10.2610	100.2615 100.3222 100.4049 100.5273	0.3118E+07 0.3118E+07 0.3118E+07 0.3118E+07 0.3118E+07	0.3123E+07 0.3123E+07 0.3123E+07 0.3123E+07 0.3123E+07	0.2444E+05 0.2444E+05 0.2444E+05 0.2444E+05 0.2444E+05	.1031E+07 0.1	00000
100.0023	000000000000000000000000000000000000000	100.0024 100.0023 100.0023 100.0049	7.2039 8.0050 8.9857 10.2545	100.2614 100.3222 100.4052 100.5267	0.3118E+07 0.3118E+07 0.3118E+07 0.3118E+07 0.3118E+07	0.3123E+07 0.3123E+07 0.3123E+07 0.3123E+07 0.3123E+07	0.2444E+05 0.2444E+05 0.2444E+05 0.2444E+05 0.2444E+05	.1031E+07 0.1	000000000000000000000000000000000000000
100.0023	0.0000 0.0000 0.0000	100.0024 100.0023 100.0023 100.0047	7.2033 8.0043 8.9892 10.2491	100.2614 100.3221 100.4055 100.5261	0.3118E+07 0.3118E+07 0.3118E+07 0.3118E+07	0.3123E+07 0.3123E+07 0.3123E+07 0.3123E+07 0.3123E+07	0.2444E+05 0.2444E+05 0.2444E+05 0.2444E+05 0.2444E+05	3) .1031E+07 0.10	000.0
100.0023	000000000000000000000000000000000000000	100.0024 100.0024 100.0023 100.0047	7.2026 8.0034 8.9929 10.2464	100.2613 100.3220 100.4058 100.5259	is: 0.3116E+07 0.3118E+07 0.3118E+07 0.3118E+07	C-2) is: 0.3123E+07 0.3123E+07 0.3123E+07 0.3123E+07	0.2444E+05 0.2444E+05 0.2444E+05 0.2444E+05 0.244E+05	(slug ft^2/sec^3) 0.1031E+07 0.1	00000
100.0023	900) 0.0000 0.0000 0.0000 0.0000 0.0001	ft/sec) ARE: 100.0024 100.0024 100.0023 100.0046 100.0019	ec) ARE: 7.2019 8.0024 8.963 10.2488 12.0109	c) ARE: 100.2613 100.3220 100.4061 100.5261	(ft~2/sec^2) 0.3118E+07 0.3118E+07 0.3118E+07 0.3118E+07 0.3118E+07	TELD (ft-2/sec 0.3123E+07 0.3123E+07 0.3123E+07 0.3123E+07 0.3123E+07	0.24448.05 0.24448.05 0.24448.05 0.24448.05 0.24448.05 0.24448.05	ENTHALPY (slug	(1/ft) ARE: 000 0.000 000 0.000 000 0.000 000 0.000
100.0023	ACITIES (ft/a 0.0000 -0.0005 -0.0001 -0.0006	VELOCITIES ( 100.0025 100.0025 100.0023 100.0045	TIES (ft/e 7.2010 8.0013 8.9990 10.2600 12.0053	IES (ft/se 100.2612 100.3219 100.4064 100.5272	THALPY FIELD 0.3118E+07 0.3118E+07 0.3118E+07 0.3118E+07 0.3118E+07	ENTHALPY F 0.3123E+07 0.3123E+07 0.3123E+07 0.3123E+07	ELD (ft-2/sec 0.2446E+05 0.2444E+05 0.2444E+05 0.2444E+05 0.244E+05	STAGNATION ENT.	CURVATURES .000 .000 .000 .000
99.9983	RADIAL VEI 0.0000 0.0000 0.0000 0.0000	MERIDIONAL 100.0007 100.0007 100.0074 99.9982	THETA VELOCI 7.2000 8.0000 9.0000 10.2857 12.0000	TOTAL VELOCIT 100.2596 100.3202 100.4042 100.5349	STATIC EN 1.3119E+07 1.3119E+07 1.3119E+07 1.3119E+07	STAGNATION 3123E-07 3123E-07 3123E-07 3123E-07	THE ENTROPY PIE 21 0.24442-05 ( 16 0.24442-05 ( 11 0.2442-05 ( 6 0.2442-05 ( 1 0.24442-05 (	MASS WEIGHTED ST 0.1031E+07 0.10	E STREALLINE 0.000 0.000 0.000 0.000 0.000
1	1748 21 11 6 11	74E 21 11 6 11	10019 10019 10019	116 116 116 116 116 116 116 116 116 116	17 10 10 10 10 10 10 10 10 10 10 10 10 10	17. 11.0 11.0 6.0	144 100 100 100 100 100 100 100 100 100	MASS 0.10	21 21 11 11 11

0.6066E-02 0.6070E-02 0.775FE-02 -6952E-01 -7116E-01 0.2824E-00 0.2937E+00 0.6091E-01 0.6166E-01	0.8110E-01 0.8110E-01 0.1240E+00 0.1240E+00 0.2367E+00 0.237E+00 0.3249E+00 0.3280E+00 0.6253E+00 0.6253E+00	0.2364E-02 0.2364E-02 0.2364E-02 0.2364E-02 0.2364E-02 0.2364E-02 0.2364E-02 0.2364E-02 0.2364E-02 0.2364E-02					0.2718E-03 0.2718E-03 0.2718E-03 0.2718E-03 0.2718E-03 0.2718E-03 0.2718E-03 0.2718E-03 0.2718E-03 0.2718E-03
0.6062E-02 0.7755E-02 6733E-01 0.2673E+00	0.8110E-01 0.1240E+00 0.2356E+00 0.3207E+00	0.2364E-02 0.2364E-02 0.2364E-02 0.2364E-02 0.2364E-02				70001	0.2718E-03 0.2718E-03 0.2718E-03 0.2718E-03
2 0.6056E-02 2 0.7755E-02 16441E-01 0 0.2472E+00 1 0.5858E-01	1 0.8110E-01 0 0.1240E+00 0 0.2342E+00 0 0.3152E+00 0 0.6253E+00	2 0.2364E-02 2 0.2364E-02 2 0.2364E-02 2 0.2364E-02 2 0.2364E-02	14.700 14.700 14.700 14.700 14.700 14.700 14.700 14.700 14.700 14.700	14.617 14.617 14.617 14.617 14.617 14.617 14.617 14.617 14.617 14.617	00000	519.671 519.67 519.670 519.67 519.670 519.67 519.670 519.67 519.668 519.66	3 0.2718E-03 3 0.2718E-03 3 0.2718E-03 3 0.2718E-03 3 0.2718E-03
0.6047E- 0.7753E- 6053E- 0.2204E+	0.8110 0.1240 0.2322 0.3080	0.2364E- 0.2364E- 0.2364E- 0.2364E- 0.2364E-	14.700 14.700 14.700 14.700	14.617 14.617 14.617 14.617	00000	519.670 519.670 519.670 519.670 519.668	0.2718E-03 0.2718E-03 0.2718E-03 0.2718E-03 0.2718E-03
0.6037E-02 0.7752E-02 5535E-01 0.1846E+00	0.8110E-01 0.1239E+00 0.2297E+00 0.2984E+00	0.2364E-02 0.2364E-02 0.2364E-02 0.2364E-02 0.2364E-03	111111111111111111111111111111111111111	****	00000	00000 00000 00000	0.2718E-03 0.2718E-03 0.2718E-03 0.2718E-03 0.2718E-03
0.6022E-02 0.7750E-02 4844E-01 0.1368E+00	0.8110E-01 0.1239E+00 0.2263E+00 0.2859E+00	0.2364E-02 0.2364E-02 0.2364E-02 0.2364E-02	.700 14. .700 14. .700 14. .700 14.	.617 14. .617 14. .617 14. .617 14.	00000	670 519. 670 519. 670 519. 670 519.	0.2718E-03 0.2718E-03 0.2718E-03 0.2718E-03
0.6003E-02 0.747E-02 0.7747E-02 3925E-01 0.7314E-01	S: 0.8109E-01 0.1239E+00 0.2218E+00 0.2696E+00 0.6252E+00	0.2364E-02 0.2364E-02 0.2364E-02 0.2364E-02 0.2364E-02	S: 14.700 1 14.700 1 14.700 1 14.700 1 14.700 1	14.617 1. 14.617 1. 14.617 1. 14.617 1.	5GATIVE 0.000 0.000 0.000 0.000	519.670 519 519.670 519 519.670 519 519.670 519	0.2718E-03 0.2718E-03 0.2718E-03 0.2718E-03 0.2718E-03
PORCE (1bf/ 0.5977E-02 0.7744E-02 2700E-01 1169E-01 0.4153E-01	(1bf/ft~2) I 0.8109E~01 0.1239E+00 0.2160E+00 0.2484E+00	C-3) IS: 0.2364E-02 0.2364E-02 0.2364E-02 0.2364E-02 0.2364E-02	(psi) I 14.700 14.700 14.700 14.700	(pei) IS: 17 14.617 17 14.617 17 14.617 17 14.617 17 14.617	NLET (ps	E FIELD (R) 10 519.670 70 519.670 70 519.670 70 519.670	S:
MECTION BODY 0.5943E-02 0.7740E-02 1069E-01 1254E+00 0.3411E-01	0.8109E-01 0.1238E+00 0.2083E+00 0.2083E+00 0.2215E+00	0.2364E-02 0.2364E-02 0.2364E-02 0.2364E-02 0.2364E-02 0.2364E-02	PRESSURE 700 14 700 14 700 14 700 14	SURE FIEL 617 14. 617 14. 617 14. 617 14.	M	670 670 670 670	VISCOSITY I 0.2718E-03 0.2718E-03 0.2718E-03 0.2718E-03
E THETA DIF 0.5896E-02 0.774E-02 0.1101E-01 2771E+00	E DISSIPATE 0.8108E-01 0.1237E+00 0.1982E+00 0.1877E+00	THE DENSITY F. 21 0.2364E-02 16 0.2364E-02 11 0.2364E-02 6 0.2364E-02 1 0.2364E-02 1 0.2364E-02	ું તે તે તે તે તે	THE STATIC PRI 21 14.617 1. 16 14.617 1. 11 14.617 1. 6 14.617 1.	CHANGE IN PRE- INCREASE IS P 21 0.000 11 0.000 6 0.000 1 0.000	E STAGNAT 519.670 519.670 519.670 519.670	THE TURBULENT 21 0.2718E-03 16 0.2718E-03 11 0.2718E-03 6 0.2718E-03 1 0.2718E-03
	THETA DIRECTION BODY FORCE (1DE/ft <sup>-3</sup> ) IS: -5898E-02 0.5943E-02 0.5977E-02 0.6003E-02 0.6037E-02 0.6047E-02 0.6056E-02 0.6062E-02 0.6066E-02 0.6070E -5898E-03 0.7946E-03 0.7746E-02 0.7747E-02 0.7775E-02 0.7755E-02 0.7755E-02 0.7755E-02 0.7755E-02 0.7756E-02 0.7755E-02 0.7755E-02 0.7755E-02 0.7755E-02 0.7755E-02 0.7755E-03 0.775E-03 0.7755E-03 0.7755	### PINECTION BODY FORCE (lbE/ft-3) IS:  1. 58948E-02 0.59948E-02 0.59948E-02 0.50947E-02 0.5047E-02 0.5056E-02 0.5056E-02 0.5056E-02 0.5056E-02 0.5056E-02 0.5056E-02 0.5056E-02 0.5056E-02 0.5056E-02 0.7056E-02 0.7056E-02 0.7156E-02 0.7756E-02 0.7756E-0	### PIRECTION BODY FORCE (1DE/FE-3) IS:  5.5958E-0.2 0.59518E-0.2 0.59518E-0.2 0.6032E-0.2 0.6037E-0.2 0.6047E-0.2 0.6066E-0.2 0.6062E-0.2 0.6062E-0.2 0.5070E-0.2 0.5978E-0.2 0.77448E-0.2	### DISSIPATION BODY PORCE (1DE/FE-3) IS:  1.5598E-0.2 0.5047E-0.2 0.5775E-0.2 0.7755E-0.2	ETHERN DIRECTION BODY PORCE (1DE/FE-3) IS:  0.55918-0.70 0.50518-0.20 0.50518-0.20 0.6052E-0.2 0.6052E-0.2 0.6056E-0.2 0.7755E-0.2 0.7755E	### PROPRIES   1.000	Column   C

0.1633E+01 0.1633E+01 0.1633E+01 0.1633E+01 0.1633E+01 0.1633E+01 0.1633E+01 0.1633E+01 0.1633E+01 .1633E+01 .1633E+01 .1633E+01 .1633E+01 0.1633E+01 THE HEAT TRANSFER COEFFICIENT IS: 21 0.1633E+01 0.1633E+01

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Joan Boggs
STINFO Program Manager